

PEST AND BENEFICIAL POPULATIONS AND RETURNS  
FROM ALTERNATIVE SMALL-SCALE CORN AND BEAN  
CROPPING SYSTEMS IN THE GUATEMALAN HIGHLANDS

By

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Abstract of Dissertation Presented to the Graduate School  
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PEST AND BENEFICIAL POPULATIONS AND RETURNS FROM  
ALTERNATIVE SMALL-SCALE CORN AND BEAN CROPPING SYSTEMS IN  
THE GUATEMALAN HIGHLANDS

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In the western Guatemalan highlands, increased cultivation of export vegetables, especially broccoli (*Brassica oleracea* L.), threatens the production of the staple food crops, corn (*Zea mays* L.) and beans (*Phaseolus vulgaris* L.), jeopardizing food security. Furthermore, it creates greater obstacles to the adoption of ecological pest management strategies due to greater dependence on synthetic pesticides. Nevertheless, small-scale farmers seeking increased income are tempted to plant these crops. Cropping patterns that maintain corn and beans for their dietary and cultural value and integrate cash crops may be more appropriate for fulfilling needs of local farmers while avoiding dependence on chemical inputs.

This project evaluates corn and beans in monoculture and in association with secondary crops chosen for their value to the farmer, nutritional contributions, and market potential. Pest and beneficial insect population densities, nematode population densities, disease, damage, and yields were

measured to determine which cropping system provides greater economic and nutritional returns without increasing key pests on the main crops.

The seasonal mean density of *Spodoptera frugiperda* (J.E. Smith) was higher in the corn monoculture than the high-risk intercrop of corn with black beans, faba beans (*Vicia faba* L.) and broccoli. Consequently, the seasonal mean percent of plants with insect damage was higher in the corn monoculture than the intercrops. No other consistent differences were detected in insect pest and beneficial populations, nematode populations, disease, damage or yield in either the corn or bean cycles. Therefore, the addition of the secondary crops tested would not increase the need for pest control in the main crops. While pest densities and damage were not high enough to warrant chemical control on corn or beans, control of pests on secondary crops in the high-risk intercrop (beans, faba beans, broccoli and tomato (*Lycopersicon esculentum* L.)) would be recommended.

The low-risk intercrop in the bean cycle, beans with husk tomato (*Physalis pruinosa*), provided greater economic and nutritional returns than the monoculture, as was so for that treatment over the year, including the corn cycle. Therefore, at least one of the alternative intercrops tested provided greater returns without increasing the need for pest control.

## CHAPTER 1 INTRODUCTION AND LITERATURE REVIEW

Changing environmental and socio-economic conditions in Central America have applied pressures to traditional agricultural production systems. Emerging needs of small-scale farmers in the region can most appropriately be met by advancing sustainable pest management approaches that are compatible with intensive production and account for the multiple objectives and constraints of the farm families involved. The study of cropping systems in Sololá, Guatemala (Figure 1-1), described here, takes one approach to such a challenge, that of analyzing alternative cropping systems for their value both in minimizing pest problems and in maximizing tangible benefits for the farm family.

### Effects of Changing Cropping Patterns on Western Guatemalan Highland Communities

Historically, intensive land management operations such as terracing and raised bed vegetable production have been prevalent in the western Guatemalan highlands, particularly in the state of Sololá (Wilken 1971, 1987, Mathewson 1984). In an early extensive study of the area, McBryde (1945) found that corn (*Zea mays* L.), the most important food plant in the country, was considered one of the principal market crops and was traded back and forth



Figure 1-1. Map of Guatemala, indicating western highlands (○) and study area (→).

between the highlands and Pacific coastal plain, due to differing harvest periods in each area. Black beans (*Phaseolus vulgaris* L.) were considered second in importance, with San Andrés Semetebaj having high-quality production, while the lowlands produced poorer quality beans and had numerous insect pests. Although climbing varieties of black beans were common throughout the region, bush varieties (*frijol de suelo*) were most common around the township of San Andrés Semetebaj, as were güisquiles (vegetable pears, *Sechium edule*). Tomatoes (*Lycopersicon esculentum* L.) were more frequently observed in the lakeshore communities, where water could easily be drawn from the lake. Potatoes (*Solanum tuberosum* L.) were grown in areas above approximately 1900 m. Habas (broadbeans or faba beans, *Vicia faba* L.) were observed planted in the *milpa* (cornfield) in San Andrés Semetebaj and separately at nearby Xepec. Anise (*Pimpinella anisum* L.) was also observed at that time, and described as a specialty crop grown almost exclusively in San Antonio Palopó and San Andrés Semetebaj. Wheat (*Triticum aestivum* L.) dominated the landscape in much of the region, closely rivaling corn in production.

McBryde (1945) also described the *tablón* (raised bed) system of vegetable cultivation in Sololá, from Panajachel to San José Chacayá. Dependent on irrigation, *tablón* production included primarily old world crops, dominated by onions (*Allium cepa* L.) and including garlic (*Allium sativum* L.), cauliflower (*Brassica oleracea botrytis* L.), carrots (*Daucus carota* L.), parsley (*Petroselinum crispum* L.), beets (*Beta* spp.), cabbage (*Brassica oleracea capitata* L.), turnips (*Brassica rapa* L.), radish (*Raphanus sativus* L.), lettuce



(*Lactuca sativa* L.) and potatoes. These vegetables were an early introduction from Europe into the area, although the *tablón* production system itself is thought to be pre-Columbian (McBryde 1945, Wilken 1971). Mathewson's (1984) later study detailing the *tablón* production system in Panajachel in the early 1980s cites the major crops as onions, garlic, strawberries (*Fragaria* spp.) and beans, with many plants intercropped with corn, including güisquil, manioc (*Manihot* spp.), sweet potatoes (*Ipomoea batatas* L.), chipilin (*Crotalaria longirostrata* Hook & Arm.), malanga (*Xanthosoma* spp.), and hierba buena (*Mentha* spp.). Finally, governmental census data revealed that 66.9% of the land in vegetable production in the area in 1979 was planted in faba beans, which has traditionally been cultivated in association with other crops, particularly corn and black beans. The other major vegetables at that time were güisquil (33%), potato (15.2%), carrots (5.0%) and onion (3.4%) (Proyecto ALA 1987).

Although a variety of vegetables has been cultivated in the region for years, not until recently did many small-scale growers in Sololá and the surrounding region begin to adopt the production of vegetables destined for export markets. Broccoli (*Brassica oleracea* L. botrytis group) has been the principal export crop, but others have been promoted, including snow peas (*Pisum sativum* L. macrocarpon group), snap beans (*P. vulgaris*) and brussels sprouts (*Brassica oleracea* L. gemmifera group) (Morales et al. 1993). Many small-scale farmers in the western highland region have altered management strategies and crop choices, as a result of increasing population and limited land, greater need for cash income due to wider integration into the economic

and political facets of the national society, and other influences of modernization. These socio-economic factors can have profound effects on traditional cropping systems (Brush 1983, Deere and Wasserstrom 1981). While increases in yields may be the primary goal for policy makers and agricultural scientists, small-scale farmers may concentrate on other objectives such as risk avoidance and food security (Caesar 1990, Clawson 1985). Furthermore, although the production of staple food crops may not always provide the full nutritional requirements of the rural family, increases in income do not necessarily lead to improved nutrition (McCulloch and Futrell 1988, Dewey 1981). In the case of small-scale highland Guatemalan farmers, the improved incomes sometimes accompanying adoption of nontraditional export agriculture have not always improved the nutritional status of children, since disproportionately greater income generation has often gone toward the consumption of non-food items. Additionally, risk is very high for these export crops, and communities in which their adoption has been prevalent often experience rapid social differentiation and shifts from family to hired labor and from subsistence farmers to wage laborers (Rosset 1991). Furthermore, communities that lose or reduce the use of traditional crops and varieties lose valuable genetic diversity and tend to lose confidence in their own knowledge and management techniques (Thrupp 1989, Bentley 1989a).

The most profound change in management, motivated in part by these cropping system changes, has been the introduction and prevalence of synthetic fertilizers and pesticides. Farmers adopting export crops tend to grow them in

monoculture with greater amounts of chemical inputs, partly because of the high cosmetic standards of foreign markets. Lack of regulation and access to information about proper use of these chemicals often leads to environmental contamination and safety risks for the entire farm household (ICAITI 1977).

Pesticide use in the region has grown substantially as a result of export crop production, and repeated detainment in the United States of products exceeding pesticide residue standards has resulted in large economic losses. Additional effects include high production costs for farmers, with the social consequences already mentioned, potential health problems, environmental contamination, and development of resistance in pest insects (Morales et al. 1993, Rosset 1991). For the individual farmer, production of broccoli and other fresh vegetables involves not only fulfilling requirements for using specified pesticides, but also a risk of crop failure or rejection by the export company. When crop loss occurs, the farmer may be left, not only with less corn, the staple crop, but with additional debts as well. Therefore, the adoption of export vegetable crops by small-scale farmers in highland communities can in some cases lead to greater economic instability, loss of integrity of the corn crop, and greater synthetic pesticide use.

#### Difficulties in Promoting Integrated Pest Management (IPM) Programs Among Resource-Poor Farmers

Pest management, as the concept of IPM was intended, involves suppressing the target population to an equilibrium level consistently below the

economic threshold through a variety of tactics, particularly the encouragement of native natural enemies (Stern et al. 1959, Stimac and Barfield 1979, Pimentel et al. 1989). Understanding the relationship between pest population densities, damage to crops, and yield is an important prerequisite to the concept of damage tolerance upon which pest management is based (Funderburk et al. 1993). IPM, a component of sustainable agriculture, has been increasingly emphasized in the field of community development, to achieve both long-term stability in production, and maintenance of environmental quality. The growing interest in agroecology-based IPM stems in part from a realization that reliance on chemical inputs is not only costly in energy and economic terms, but can lead to environmental, health and social degradation (Gliessman 1992, 1988, Altieri 1987, Edwards et al. 1993, Pimentel et al. 1989).

Conway (1987, 1994) defines sustainable agriculture within the context of agroecosystem properties (productivity, stability, sustainability and equitability), involving trade-offs in terms of social value. Compatibility with traditional social patterns, conservation of natural resources, and potential for long-term improvement in food production make it an important component of small-farmer development. However, a major obstacle to the promotion of IPM within sustainable agriculture is the lack of controlled field experiments conducted locally and combining traditional knowledge and community needs with scientific knowledge of ecologically-based pest management strategies (Bunch 1982, Altieri 1987, Brookfield and Padoch 1994, Woodley 1991, Thrupp 1989).

Dependence on chemical pesticides must be broken for ecologically-based pest management strategies to be effective. One of the major problems facing small-scale agriculture in Central America is the misuse of pesticides. A lack of regulation of products and of extension information on proper use puts both the farm household and the environment at risk (ICAITI 1977, Popper 1994). Small-scale farmers have readily accepted synthetic pesticides because of the simplicity of their use and immediate effects (Barfield and Swisher 1994, Escalada and Heong 1993). However, misconceptions about the health effects of highly toxic compounds and lack of knowledge of proper usage (for example, insecticides used to combat fungal problems, and dosage based on the number of pests seen) have been documented in eastern Guatemalan communities and are not uncommon throughout the region (Popper 1994).

The reliance on pesticides as a result of the promotion of nontraditional export agriculture in Central America has contributed not only to ecological problems such as contamination of soil and water, but also to a wealth of problems for the small-scale producer, including pesticide resistant populations and secondary pest outbreaks, with resulting crop losses. Small-scale farmers tend to be disproportionately affected by these and other consequences of pesticide dependence, since they tend to lack the knowledge necessary to understand the risks involved (Rosset 1991, Murray 1991). Expectations of traditional farmers regarding the value of pesticides tend to be unrealistically high, further exacerbating the problem (Thurston 1992). Additionally, the

acceptance of certain damage levels inherent in IPM may not be compatible with farmers' perceptions of crop loss (Goodell 1984).

Furthermore, gaps in farmer knowledge of phenomena not easily observed, such as insect life history stages, or parasites and predators, has made IPM programs slow to implement in Central America (Andrews et al. 1993; Bentley and Andrews 1991; Bentley 1989b). One of the most critical obstacles for the promotion of IPM among small-scale farmers is that of access to information. IPM is knowledge intensive, and extensive training is required, especially for small-scale tropical farmers (Odhiambo 1990, Goodell 1984). Not only is it difficult for farmers to develop a complete understanding of the concepts of IPM, but its implementation requires scientists and extension agents to have ample site-specific ecological information on pest populations (Barfield and O'Neil 1984, Poswal et al. 1993, Goodell 1984). Such information is rare for the western Guatemalan highlands. Therefore, the change to export vegetables has potentially serious consequences for the adoption of ecological pest management strategies in the area.

#### Choosing Crops with Minimal Pest Problems as a Pest Management Strategy

Traditional farmers have developed a variety of means of avoiding pests in their agroecosystems (Barfield and Swisher 1994). For example, avoiding specific pests by planting at the time of year when they are not prevalent is one form of cultural pest management. The use of cultural controls such as crop rotations and intercropping has been successfully implemented in some

situations where the goal was to reduce or completely eliminate the use of chemical pesticides (Flint and Roberts 1988, Theunissen 1997). In many cases involving small-scale resource-poor farmers, the lack of skills to adequately handle chemical pesticides has led to recommendations for developing alternatives involving multiple cropping and other cultural controls (Seshu Reddy 1990, Saxena et al. 1989). Given the previously discussed negative impacts of pesticide dependence on small-scale farmers in Central America, and the difficulties in implementing ecologically-based IPM programs, the most appropriate pest management tactics for these farmers are those that avoid pests to the greatest practical extent.

One way to avoid pests and simultaneously address the need for greater productivity is to design intercrops utilizing the staple food crops as the main crops and income-generating or additional food crops as the secondary crops, chosen for minimal potential pest damage. Plants native to an area may have higher resistance to insects and disease, since they have adapted to local environmental conditions (Altieri et al. 1987). Several traditional crops in Guatemala are potential candidates for inclusion in such cropping systems.

#### Minimizing Pests in Crop Combinations

In advancing beyond the simplistic reduction of pesticide use by eliminating "calendar spraying," the study of IPM is increasingly directed toward greater ecological understanding. As a component of IPM and of sustainable agriculture, cultural pest management through habitat manipulation has received

heightened attention. In the past several decades, we have seen a surge of studies exploring herbivore and natural enemy responses in mixed cropping systems (see, for example, Coll and Bottrell 1994, Elstrom et al. 1988, Tingey and Lamont 1988, Perfecto and Sediles 1992, Letourneau 1987, Risch 1981, Tonhasca 1994; for detailed reviews, see Cromartie 1991, Sheehan 1986, Risch et al. 1983, Russell 1989, Tonhasca and Byrne 1994, Perrin 1977).

Root (1973) offered two hypotheses to explain the reduced abundance of herbivorous insects often found in vegetationally diverse habitats. The natural enemies hypothesis attributes such reductions to greater favorability of a more diverse habitat for natural enemies, due to provisioning of nectar and alternate prey, shelter, microclimatic variation, and allelochemical attractants (Gross 1987, Price et al. 1980, Altieri et al. 1981). The resource concentration hypothesis alternatively attributes the same phenomenon to the tendency of herbivores to remain longer in habitats with concentration of their food plant, whereas more diverse habitats may disrupt herbivore colonization, movement, and reproduction (Kareiva 1985, Perrin and Phillips 1978, Feeny 1976, Andow 1990).

The relative contributions of the resource concentration and enemies hypotheses to herbivore response in polycultural agroecosystems have been frequently debated. While it is often noted that they are not mutually exclusive (e.g. Russell 1989), it has been suggested that the resource concentration hypothesis is more applicable to annual crops in polyculture, while the enemies hypothesis better explains herbivore response in perennial cropping systems (Risch et al. 1983, Baliddawa 1985). In addition, monophagous pests tend to be



more abundant in monocultures, while the abundance of polyphagous pests may vary, depending on the relative importance of natural enemies versus herbivore movements (Risch et al. 1983).

Beyond these broad generalizations, few studies have attempted to define the specific mechanisms resulting in lower herbivore abundance in some polyculture systems, primarily because of the large number of factors involved in more complex agroecosystems. For example, the responses of both herbivores and natural enemies have been hypothesized to depend on their particular life history traits (e.g., generalist predators may be more effective in vegetationally diverse habitats than specialist natural enemies (Sheehan 1986)), as well as on the particular spatial and temporal arrangements of the agroecosystem (e.g., some generalist predators may respond to plant density independent of plant diversity (Letourneau 1990)). In addition, semiochemicals emitted by associated nonhost plants may influence an herbivore's attractancy to its host plant (Price 1981). Size of the field, field borders, time between plantings, susceptibility of crop varieties, ability of the pest or natural enemy to disperse and life cycle of the insects are just some examples of factors that have been hypothesized to influence the abundance of pest insects in vegetationally diverse agroecosystems (Litsinger and Moody 1976).

Therefore, the effects of vegetational diversity on insect pests remain unclear, and the multitude of empirical studies lack an integrating organizational context, making them inadequate for addressing the ecologically-based goals of pest management. Andow (1991a) reviews the empirical and theoretical

approaches to comprehending the frequently cited lower herbivore densities in polyculture systems, but cites a lack of sufficient understanding required for predictions useful in pest management, especially for predicting when natural enemies are most significant in reducing herbivore densities. Moreover, most analyses of insect populations in mixed cropping systems fail to evaluate subsequent effects on crop yields (Risch 1983, Andow 1991b).

In addition, trying to understand the manipulations of the agroecosystem that would favor low equilibrium pest densities becomes more difficult in small-scale tropical agroecosystems, which tend to be more complex than their temperate counterparts, involving more diverse and intensively managed components adapted to local conditions (Francis 1985, Jodha 1980, Hildebrand 1976). Therefore, the most comprehensive approach to IPM studies involves understanding manipulations of pest habitats, and constructing models to sort out the ecological interactions that may lead to additional pest management options (Matteson et al. 1984). The construction of simulation models would allow the examination of many combinations of management strategies, which would be impractical through empirically-based experimentation alone (Stimac 1993, Foster and Ruesink 1986). In addition to predicting the conditions under which pest populations are lowest, it would also allow us to continually update our understanding of the system in the face of changes in the environment, management, and socio-economic components of the cropping system.

The complexity of agroecosystems that makes modeling desirable also makes it impractical in the short term, in part because a surprisingly small

amount of information on local occurrence of economically important species is available. In the Central American region, while data on local pests has been accumulated in Honduras (Andrews and Quezada 1989), Costa Rica (King and Saunders 1984) and the Caribbean basin (Schmutterer et al. 1990), virtually no comparatively detailed studies have been conducted in Guatemala. While some entomological studies have therefore been carried out in neighboring countries, there is little available evidence of the extent to which the potential colonizing pool or pest complex on any particular crop may correspond to that found in Guatemala, and specifically to the western highland area. There is a great need for characterization of arthropod communities in local agroecosystems and for future research projects, such as the establishment of economic thresholds through quantitative studies, to be organized and prioritized before more comprehensive understanding of agroecosystems can be pursued.

Therefore, the accumulation of sufficient knowledge to develop a detailed understanding of small-scale tropical agroecosystems is a long-term goal that is not suitable for resolving pressing concerns. While achieving greater ecological understanding is an important goal of IPM that should continue to be pursued through such areas as modeling of agroecosystems, there is also a more immediate need for knowledge of pests and beneficial insects in local cropping systems so that appropriate choices can be made now. Empirical studies that compare a limited number of choices, while not able to address the ecological

roots of pest population response, are more practical for offering guidelines to address the immediate concerns of farmers.

#### Maximizing Farmer Acceptance by Tailoring Cropping Systems to Maximize Farmer Benefits

Although some intercropping systems have been studied in detail to determine the effects of increased crop diversity on pests and beneficial insects, the choice of cropping systems by small-scale farmers is usually based on factors other than pest control. Therefore, for alternative cropping systems to be adopted, they must not only be ecologically sustainable, but they must also demonstrate tangible benefits to the farm family (Edwards et al. 1993). In contrast to agricultural technologies intended for large farms, ecologically-based pest management, as a component of vegetationally diverse agroecosystems, is compatible with the culture and objectives of traditional farmers.

Some development projects have incorporated indigenous agricultural knowledge and/or traditional food crops to increase agricultural diversity, reduce pesticide use, minimize risks and make better use of local resources. The most successful of these projects aim to help resource-poor farmers improve the overall productivity of their farms, reduce dependence on chemical inputs, and achieve food self-sufficiency (Altieri 1992). Additionally, those that are easily adapted to local conditions and production methods are most often embraced. For example, an intercropping project in El Salvador aiming to increase rural incomes and improve production of basic grains and vegetables was well

received, a prerequisite to being effective, because it was based on the dietary staples of the farmers and utilized the technologies to which they were accustomed (Hildebrand 1976).

Furthermore, the objective of long-term stability in yields, achieved through diversity within the agroecosystem, is more important to traditional farmers than the maximization of yields achieved through the use of external inputs (Altieri 1991b). Yield stability is an important goal of sustainable agricultural systems. In fact, the development of ecologically and socio-economically sustainable agricultural production systems that minimize external inputs has been proposed as the most appropriate means of fulfilling the objectives of traditional farmers in the tropics (Francis et al. 1986). Such sustainable systems often include multiple cropping, which, in addition to reducing risk for the farmer, can utilize local resources efficiently, an important consideration in providing for the needs of small-scale farmers (Gliessman 1992).

The economic effects of multiple cropping systems on the farm family are a key element in determining the feasibility of particular crop combinations (Hildebrand 1976). It is important to consider not only differences in pest densities among alternative cropping systems, but also effects on yield and subsequent profit. Furthermore, different combinations of crops may yield different quantities of protein and net calories for the farm family, and the nutritional consequences of changing cropping systems should not be

overlooked (Dewey 1981). These economic and dietary returns can be used as indicators of benefit to the farm household.

Many traditional crops from Mesoamerica have nutritional and economic potential for small-scale multiple cropping systems (FAO 1993, Hernández Bermejo and León 1994). The challenge is to design sustainable intercropping systems utilizing crop combinations that, in addition to minimizing pest problems and subsequently reducing pesticide use, can provide perceivable benefits to the farm family by generating cash income, reducing risk, and improving dietary security.

### Study Objectives

The research project described here starts with the farmer-oriented justification of using intercrops for their economic and nutritional productivity and seeks to confirm that for the specific alternatives tested, pests will not be increased so much as to offset the economic and social benefits derived from the system. The project was comprised of two main components. The first phase involved a survey of the agroecological conditions of farming communities in the study area and an exploration of farmer perceptions of current and alternative production systems. Objectives of the first phase were:

- 1.) to define the constraints within which small-scale farmers in the study area operate;

- 2.) to learn which crops are preferred by local farmers and why they choose to grow particular crops, including their relative nutritional, economic and cultural values; and
- 3.) to identify appropriate crop combinations hypothesized to provide greater overall benefit to the farmer than corn and beans alone, for field experimentation during the second phase.

The second phase of the project involved field trials comparing alternative intercrops to monocultures of corn and beans, the dietary staples. It was intended to test the ability of selected alternative intercrops to provide economic and nutritional benefits to the farm household while minimizing pest problems. Specific objectives of this phase were to determine if:

- 1.) the densities of key pests or beneficials (including insects, diseases and nematodes) on corn and beans change when selected secondary crops are added to the system;
- 2.) pest damage or yields of corn and beans change when selected secondary crops are added to the system;
- 3.) adding selected crops increases the likelihood of pest control applications; and
- 4.) intercropping corn and beans with selected secondary crops can provide greater economic, nutritional and/or energetic returns than the respective monocultures.

Cropping systems in which additional crops are combined with corn and later beans may be able to alleviate some of the risks and social problems

associated with export crops, maintain cultural traditions so important to the survival of the Mayan people, and provide greater returns to the family than the traditional corn and bean cropping systems. The trend toward monoculture-based, pesticide-laden export agriculture by farmers in the Guatemalan highlands may be countered by providing indigenous populations with results of locally-derived studies documenting the effectiveness of food and market crops in polyculture. By involving analyses of specific crop combinations with respect to economic competitiveness and ecological pest control, the project may provide an example of how small-scale farmers in the western Guatemalan highlands can improve their economic and nutritional state while avoiding chemical inputs incompatible with their environmental and social interests.



## CHAPTER 2 ASSESSMENT OF AGRICULTURAL PRACTICES AND FARMER PERCEPTIONS IN THE STUDY AREA

### Introduction

Poorly distributed land, growing population, and a largely impoverished rural population in the western Guatemalan highlands have all contributed to agricultural systems that are pressuring the natural resource base (Colchester 1991, Southgate and Basterrechea 1992, Ruano et al. 1991). In addition, increased production of high-value horticultural crops in the highlands has led to pesticide contamination in the capital city's drinking water and unknown but potentially serious health problems for farmers untrained in the safe handling of pesticides (Southgate and Basterrechea 1992). In order to resolve the environmental and socio-economic conflicts inherent in changing cropping patterns, not only must technical alternatives be available, but they must also be evaluated within the context of the production systems of the farmers involved.

Small-scale, resource-limited farmers in tropical countries have evolved complex ecological and social systems. As a result, they usually have multiple objectives, including generation of both food and cash, avoidance of risk, and minimization of production inputs (Francis 1985). Traditional farmers efficiently allocate the production factors available to them (Schultz 1964), but the lack of availability of such factors is often overlooked. Additionally, the varied

objectives of traditional farmers often lead to maintenance of practices thought by agricultural scientists to be inefficient. For example, many Guatemalan farmers choose lower-yielding varieties of corn because their livestock prefer the leaves and husks of local varieties to higher-yielding hybrids (Altieri 1984b). Agricultural technologies that do not account for the constraints of small-scale farmers, nor recognize the heterogeneity of traditional agricultural systems, may not utilize local resources efficiently (Altieri 1984a, Fujisaka 1991) and may be rejected by the farmer.

Gladwin (1989) used a decision model to explain how traditional Malawi farmers decided whether to use organic versus chemical fertilizers, concluding that lack of capital and credit were more important constraints to the use of chemical fertilizers than indigenous beliefs about organic fertilizers. Furthermore, the farmers used a combination of fertilizers when possible, because within their knowledge system, each has its role in plant nutrition and soil maintenance. An increasing number of studies examining indigenous knowledge systems have concluded that the most appropriate agricultural technologies for traditional farmers are those that are developed within, or incorporate, indigenous knowledge systems. It is particularly important to maintain the traditional ecological knowledge that allows farmers to manage their resources in an environmentally sustainable way (den Biggelaar 1991, McCorkle 1989, Field 1991, Woodley 1991, Gliessman 1980; Gliessman et al. 1981). Agricultural development projects that try to replace traditional technologies rather than use them as a foundation for improvement are more

likely to fail (Goldman 1991, Groenfeldt 1991, Altieri and Anderson 1986; Altieri 1984b).

On the other hand, where technological developments have been incorporated into traditional systems, small-scale farmers have often accepted both. For example, selection and management of traditional maize varieties in Chiapas, Mexico, has continued within the context of technological changes (Bellon 1991). Taking into account the ecological and socio-economic conditions of small-scale farmers is essential to avoiding rejection of newly generated technologies. For any planned community intervention, an understanding of the knowledge, attitudes and perceptions of the target group permits the identification of possible impediments to acceptance, and when such factors are incorporated, projects can be made more successful (see, for example, descriptions of malaria and onchocerciasis interventions in Guatemala: Richards et al. 1991, Ruebush et al. 1994a, 1994 b).

The same can apply to pest management recommendations for small-scale tropical farmers, whose traditional systems may have inherent pest management characteristics such as plant resistance or natural control by predators and parasites. The traditional systems must be conserved, while at the same time improved upon (Matteson et al. 1984). In order to do so, the pest problems of the farmers must be placed in the wider context of their entire farming system (Altieri 1984b), and the conditions and constraints under which they make decisions must be clarified.

A survey of the agronomic, socio-economic and cultural conditions of small-scale farmers in the western Guatemalan highlands was carried out to identify both the most appropriate cropping systems that control pests and provide for farmers' needs, and the possible constraints to the adoption of new agricultural technologies in the communities studied. The ultimate goal of the project was to evaluate possibilities of incorporating secondary crops into the traditional corn and bean cultivation systems without increasing pest problems. The survey was conducted not only to examine local production practices, but also to explore knowledge and attitudes of farmers about traditional and non-traditional cropping systems, the practice of intercropping, and pest management, particularly the role of beneficial insects in the agroecosystem. An understanding of these issues can aid in the identification of appropriate cropping systems to be tested in the field and can also provide insight into possible obstacles to farmer acceptance of alternative cropping systems.

### Methods and Materials

Semi-structured, open-ended interviews, discussions with key informants, field observations, and an informant ranking exercise were conducted between May and August of 1995 in the two highland communities of San Andrés Semetebaj and San José Chacayá, both in the department (state) of Sololá. An additional exercise on recognition of insects found in local agricultural fields was carried out in Peña Blanca, a village under the jurisdiction of the state capital of Sololá, in March of 1997.

The majority of the survey was conducted in the *municipio* (township) of San Andrés Sémetebaj, including nine of its surrounding *aldeas* (villages). This community borders an export vegetable growing region in the state of Chimaltenango, and so has experienced greater influence of broccoli production, but it maintains many of the traditional production patterns as well. Its elevation (ranging from 1982 m in the town center to about 2200 m in some *aldeas*) and rainfall (average precipitation of 1409 mm annually) are intermediate for the region, and its social conditions are representative of those of many towns in the area (approximately 10% of rural homes have electricity and 15% have running water) (Proyecto ALA 1987). Some time was also spent in the more isolated *municipio* of San José Chacayá (elevation 2205 m), with the hope of observing more traditional agricultural practices in terms of cropping patterns and pest management. Ninety-four percent of the population of the state of Sololá is indigenous, and the predominant ethnic group in the communities studied is Cackiquel. Annual mean temperatures in Sololá range from 15.9 to 22.6 °C (Proyecto ALA 1987). McBryde (1945) described highland soils as loamy, with more clay present than in the lowlands.

#### Semi-Structured Interviews and Key Informants

A total of 105 men were interviewed by walking through local fields, approaching farmers working there, and asking through a local translator (Spanish-Cackiquel) if they would participate. The translators (one for each of the two townships) were chosen for both their roles as local farmers and their

inside knowledge of the communities. The presence and participation of a respected member of the community was more conducive to cooperation on the part of informants.

Questions were posed to participating farmers about the crops they grow, the amount of land in each, management practices (planting and harvesting dates, spacing, irrigation, weeding, fertilizer applications, crop residue management, rotations, slope management), markets, and source of technical advice, with ensuing open-ended conversation of their general concerns and interests with respect to agriculture. Interviews also included questions about pests and diseases observed and the resulting damage to crops, particularly insect pests and their chemical and non-chemical management on each crop, as well as pest occurrences in the past.

To understand crop choice, including the inherent cultural value of certain crops, interviews included discussion of opinions about traditional and non-traditional crops, opinions and experience with intercropping, and the use of native herbs as volunteers within the cropping system. Other important decisions included what additional crops were grown in the past and reasons for changing, why certain crops are chosen, and particularly why some farmers have begun to produce export crops. Farmers varied greatly with respect to degree of confidence and willingness to discuss their concerns. As a result, interview durations ranged from 10 minutes to 2 hours, with most lasting between 20 and 30 minutes.

In addition, 21 women from farming households in San Andrés Semetebaj were interviewed after approaching them in their homes, generally adjacent to or near agricultural fields. A local female translator was chosen for these interviews for the reasons cited above, as well as to increase trust by having a woman they knew pose the questions. Women were questioned about the crops their family grows, the use of native herbs in the family diet, and their concerns related to agriculture. Although crop management was not discussed in detail with the women, more time was generally spent during these interviews than for the interviews with men.

For the total of 136 interviews, questions about crops and their management, opinions, experiences, and information sources were tabulated by number and percent of informants giving each response. Finally, with the assistance of the translators, several key informants were identified, who through repeated discussions provided more in-depth insights concerning the conditions and perceptions in local farming communities.

### Crop Preference Ranking

To understand crop preferences in these communities, a preference ranking exercise (Weller and Romney 1988) was conducted in both communities, with a total of 50 informants (7 men and 16 women in San Andrés Semetebaj and 18 men and 9 women in San José Chacayá). Twenty-nine crops were selected from a list of those discussed during interviews and depicted on index cards. Each informant (again with the assistance of a local translator) was

then asked to make three piles: highly preferred crops, least-preferred crops, and intermediate crops. For each pile, informants then placed the cards in order by preference, and the overall order was confirmed. Results were tabulated for women and men in each of the two communities, providing a list of crops ranked from most preferred to least preferred.

### Recognition and Perceptions of Insects in Local Cropping Systems

Nineteen informants from the village of Peña Blanca were approached as described for the open-ended interviews. Each was asked if he/she was willing to participate in an exercise involving identifying and describing insects presented. For each pinned insect observed, informants were asked to name it and describe what it does.

The exercise was designed to explore knowledge of pest and beneficial insects present in local agroecosystems. The insects included 3 major pests, 8 minor pests and 9 beneficials, all commonly found on local crops, especially corn. If pest management were a part of the traditional knowledge base, it would be expected that informants would be able to assign the proper ecological role to particular insects, although not being able to name them specifically. Results were tabulated by mean proportion of pests and beneficials correctly identified.

### Soil and Botanical Analyses

Soil in each community was collected from 4 agricultural fields representative of the conditions and crops grown, and analyzed by a private soil



testing laboratory in Guatemala City (Agri-Lab) to determine texture, pH and nutrient levels. Thirteen commonly cited native herbs were collected, labeled with common names given by key informants, and identified to species by staff of the Herbarium UVAL, Institute of Research, Universidad del Valle de Guatemala.

## Results and Discussion

### Agronomic Conditions, Crops, Yields and Management Practices

Analyses of soil samples in both communities showed the presence of sandy loam soil, with average content of clay 15.5%, of sand 72.3% and of silt 12.3%, for the 8 samples analyzed. Average pH was 5.8, with the range between 5.2 and 6.6. The presence of sandy loam soils in all soil samples taken suggests that soils in the area are well drained and easily worked but may lose nutrients and dry out quickly. These soils may also need a significant addition of organic matter to maintain or improve the water and nutrient-holding capacity, which may explain why local growers frequently complained that soil fertility had declined since the use of chemical fertilizers became widespread. The slightly acidic pH of all of the soil samples indicates that the pH range of soils in the area is generally appropriate for most crops.

Most farm families in both communities have limited land available for cultivation, with over two-thirds reporting less than 1 ha. and one-third reporting less than 0.5 ha. (Figure 2-1). When questioned about crops they produce, farmers described a variety of grains and vegetables, whose planting seasons

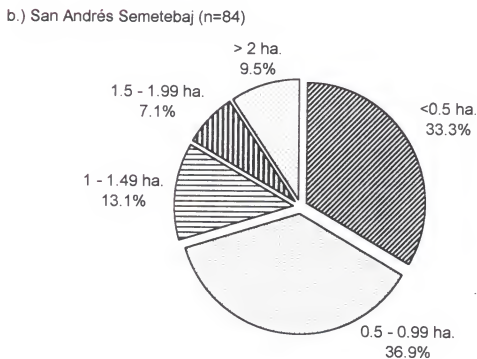
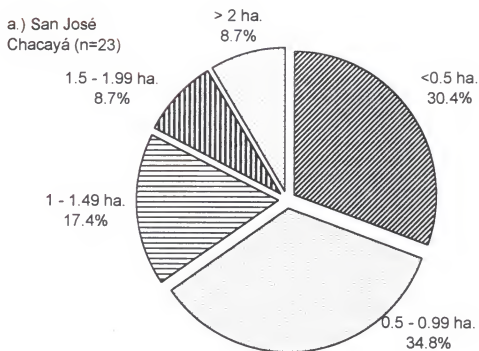
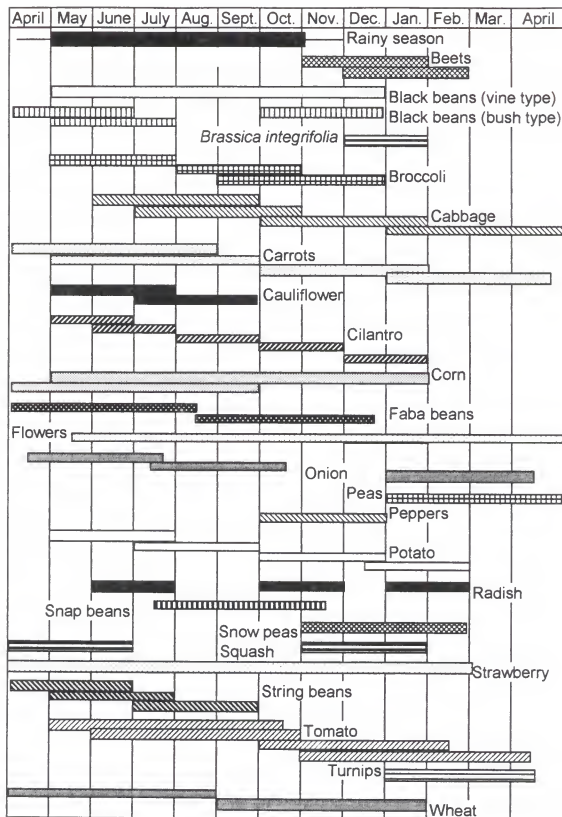


Figure 2-1. Land area available to farm families, by percent of farmers responding. a.) San Jose Chacayá; b.) San Andrés Semetebaj.

are depicted in a cropping calendar for the area (Figure 2-2). Corn and black beans are the principal crops, in terms of both percent of land area planted to them and percent of farmers planting them, which was nearly 90% for corn (Figure 2-3). Yields as reported by the farmers are given in Figure 2-4. These values represent approximations, since many farmers do not measure their yields.

Local farmers often complained about the difficulty in continuing to produce corn because of the high cost of fertilizers and the low market price. Many said they have either taken some land out of corn production for other crops, or are considering doing so. Nevertheless, corn still dominates the landscape. More than half of the land cultivated by the interviewed farmers is planted to corn, most of it for home consumption (Figure 2-3). Local varieties of corn are used almost exclusively, with most farmers keeping seed from the harvest to plant the following year. These varieties are generally planted in early May and harvested in December or January. Although short-season, hybrid varieties are available, the grain produced from them does not store as well, and the tortillas produced become too hard when re-heated. In addition, local varieties are said to be resistant to drought and to an overabundance of rain. Besides the advantages for the farm family, the continued production of local varieties of corn is important for the conservation of genetic resources they contain (Brush 1986). According to the farmers interviewed, security is another major reason for growing corn, providing food in the absence of other opportunities. For example, when there is rainfall for an entire month, as



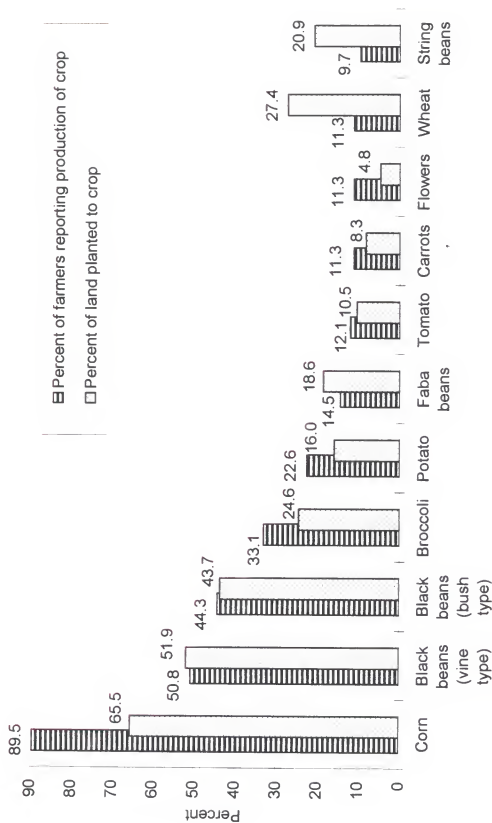


Figure 2-3. Percent of interviewed farmers in two Sololá communities reporting production of local crops (n=125), and of those reporting production, mean percent of each farmer's available land planted to each crop.

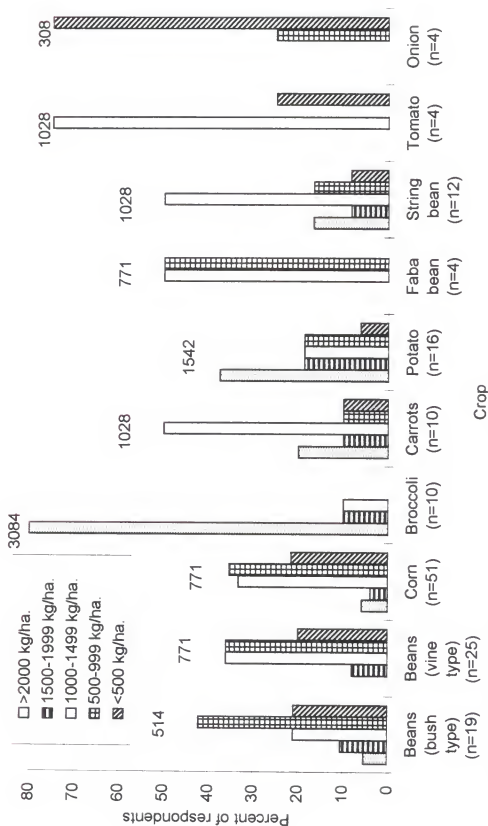


Figure 2-4. Yields of principal crops reported by farmers in two Sololá communities. Numbers above each crop represent median values.

occasionally occurs, other crops are lost and no agricultural wage work is available, but those who have planted corn still have food.

Black beans are often planted in the inter-row space, especially in San Andrés Semetebaj, and in both communities a traditional variety of climbing black bean is planted with each corn plant. Four to 5 seeds of corn and 3-4 of beans are planted in each hole, usually at a 1-m distance between rows and plants, although some use spacing of 0.75 m. Planting, weeding and harvesting are performed by hand. A broad hoe and/or machete are used for weeding, which is usually completed once a month for the first 3 months. At the second weeding, some soil is built up around each growing corn plant, and at the third weeding, soil is pushed toward the base of each plant to form mounds, a process known as the "*calzada*," literally "putting shoes on" the corn plant.

Nearly 100% of farmers interviewed used chemical fertilizers, and over 90% used chemical pesticides on at least one of their crops. However, over half also utilized crop rotation, intercropping, organic fertilizers, incorporation of crop residues, or a combination of these (Figure 2-5). Many farmers expressed the desire to learn more about organic fertilizers such as compost and manuring, and pesticides they could make from plant extracts. Many mentioned that while they had not bothered to utilize the manure from their animals since the introduction of chemical fertilizers, they were now realizing its value and beginning to use it again. Such realizations appear to be due in part to the growing number of organizations that have become involved in promoting organic agriculture in Guatemala during the last few years, with extension work

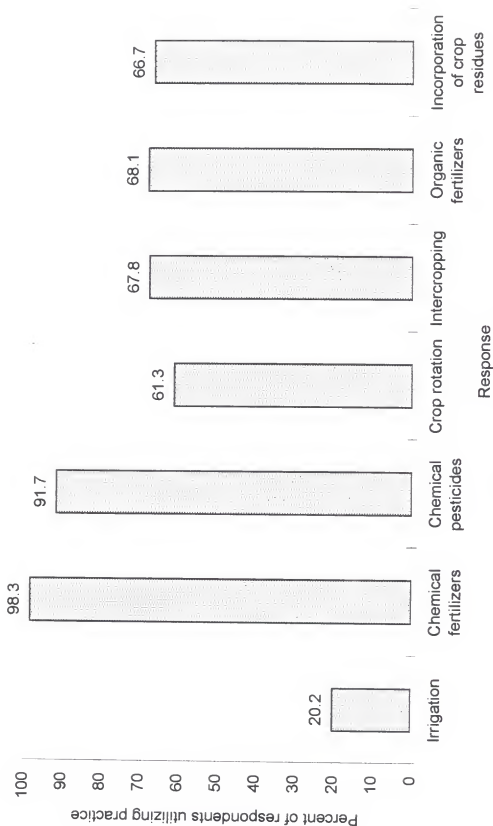


Figure 2-5. Management practices utilized by farmers in two Sololá communities.



relating to natural pesticides, composting, and intercropping. During interviews, many farmers in the San Andrés Semetebaj area discussed contacts with such groups, indicating an overall positive experience. Local agricultural cooperatives were also selling chicken manure for the first time in 1995.

Irrigation, while common in San José Chacayá through a traditional system of canals that channel water from the local river to fields, is currently rare in San Andrés Semetebaj. Only 20.2% of farmers in both communities have access to irrigation systems. However, both overhead sprinkler irrigation and hand pumps have been increasingly promoted by some organizations, with irrigation projects planned for San Andrés Semetebaj. Those without access to irrigation plant according to the rainy season, which begins in May (occasionally in April) and ends in November, with heaviest rains usually occurring in September and October following several rain-free weeks in August.

Since neither of the abovementioned communities has its own market, most crops are sold in nearby markets, notably Panajachel and Sololá. Many growers in San José Chacayá sell their vegetables in Guatemala City, especially potatoes, string beans (*P. vulgaris*) and cabbage. Broccoli in San Andrés Semetebaj is sold almost exclusively through local cooperatives that contract with export companies.

#### Attitudes and Perceptions of Cropping Systems

To better understand locally cultivated crops and how they are valued, perception and experience with certain crops was discussed during interviews.

The choice of what crops to plant each year can be complex for small-scale farm families. Gladwin's (1980) analysis of this decision by highland Guatemalan farmers revealed a number of conditions that must be met at each of several stages for particular crops to be chosen, including demand, climatic and agronomic requirements, knowledge, time, and capital or credit. When asked how they decide which crops to grow, 45.9% of respondents in the present survey cited market prices. Other important considerations were family tradition and the security of corn and bean production for the family diet (Figure 2-6). In fact, risk aversion is often a factor in production decisions of small-scale farmers (Altieri and Trujillo 1987, Marten and Saltman 1986).

Farmers repeatedly emphasized during the interviews that they are seeking income-generating crops to avoid selling the corn, which is very low in price and is needed for family consumption. They also want to avoid the use of purchased fertilizers and pesticides, which they see as very expensive and increasingly problematic. Many said that the chemical fertilizers were weakening the soil, while chemical insecticides cause health problems and do not always work well against the target pests. For those who grew different crops in the past, the question of why they changed was posed. The most frequent answer was that they had heard from others (friends, neighbors, company or extension agents) that it was profitable. When the prices of the crops they were currently growing dropped, there was greater incentive to change crops (Figure 2-7). In San Andrés Semetebaj, many families changed

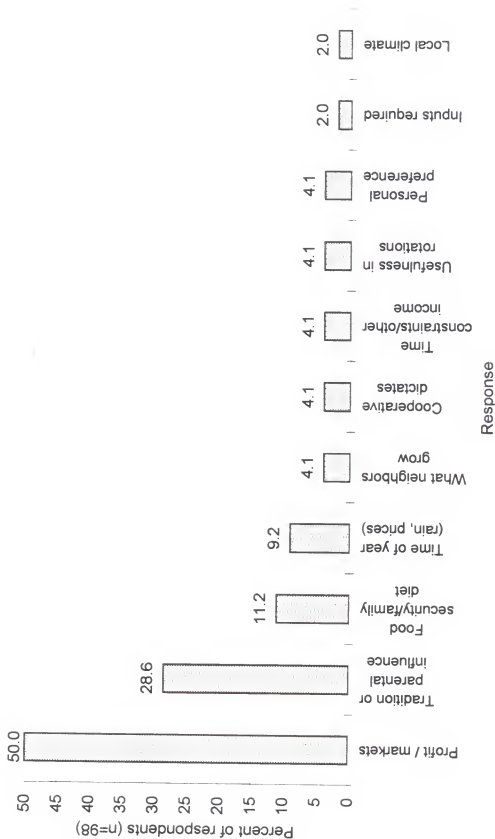


Figure 2-6. Responses to open-ended question of basis of decision on what to plant, posed to farmers in two Sololá communities.

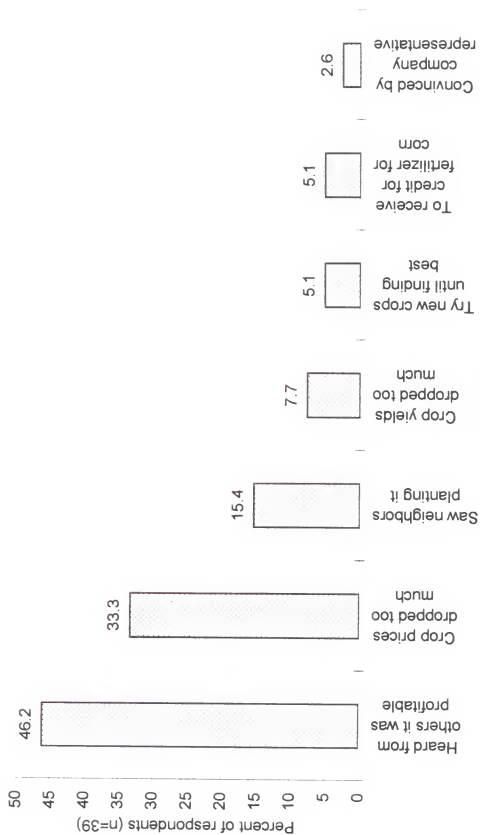


Figure 2-7. Responses to open-ended question of reasons for changing crops, posed to farmers in two Sololá communities.

part of their production from wheat to nontraditional export crops when the yields and prices of wheat dropped.

Traditional crops were associated most frequently with low market prices (38.8 % of those responding). They were also commonly seen as necessary in providing food and therefore valued in the local diet, important to the culture and tradition, and increasingly unaffordable to grow because of high input costs (Figure 2-8). Besides being essential as a dietary staple, corn is an integral part of the mythology and religion of the Mayan culture (Bukasov 1981, Johannessen 1982).

Despite the high value placed on the corn crop, many have put some of their land into cash crops, particularly vegetables. Local farmers related that export company representatives told of the high profits they would obtain by planting first brussels sprouts, then snap beans, and most commonly, broccoli. The first two were dropped from production when farmers experienced losses instead of the new house or car promised by company officials. Broccoli, however, remained popular, because some farmers have been able to make a profit, and the hoped-for good year keeps many trying to grow this crop. Thirty percent of those giving their opinion on nontraditional crops like broccoli said they can provide a profit. According to average yields and prices of both corn and broccoli reported by local farmers, the net profit is actually much higher for broccoli than for corn when the entire broccoli crop is sold, even accounting for higher input costs for broccoli. The corn crop offers almost no profit when sold,

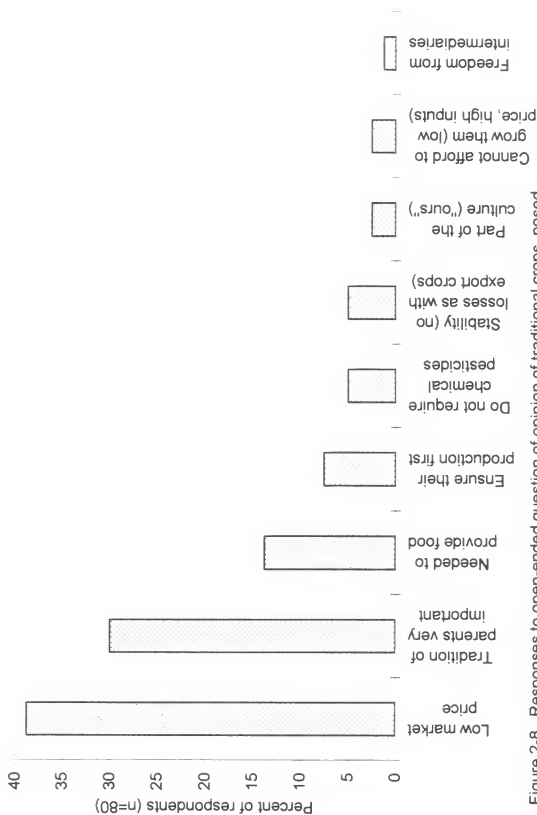


Figure 2-8. Responses to open-ended question of opinion of traditional crops, posed to farmers in two Sololá communities.

and the relatively higher price for broccoli makes it appear promising, in spite of not being a consistently profitable crop.

When asked their opinion of production of export crops like broccoli, although mention was often made of the sometimes higher returns cited above, many noted the higher expense of inputs, the greater problems with pests and subsequent need for more pesticide applications, and the requirements of more time, effort and knowledge than with traditional crops (Figure 2-9). The major problem with broccoli production, according to those interviewed, is the risk of rejection of the harvest if insect presence (lepidopteran larvae) exceeds the standard set by the export company. When part or an entire harvest is rejected, the farmer often incurs a debt to the company because of inputs bought earlier on credit.

Another criticism made by farmers is that the local agricultural cooperatives through which the export companies work sometimes do not pay for the harvest until the following year, and rumors of corruption in at least 1 cooperative were prevalent. Some of the cooperatives require associates not only to grow broccoli to maintain membership (and receive credit for fertilizers for corn) but also to buy from them the complete input package, including in some cases excess amounts of pesticides, in order to guarantee purchase of the harvest. Finally, broccoli and other exotic export crops require more fungicide and insecticide applications, because of greater pest prevalence than traditional crops and higher market standards. Agricultural credit requirements tied to pesticide use are not uncommon in Central America (Thrupp 1990).

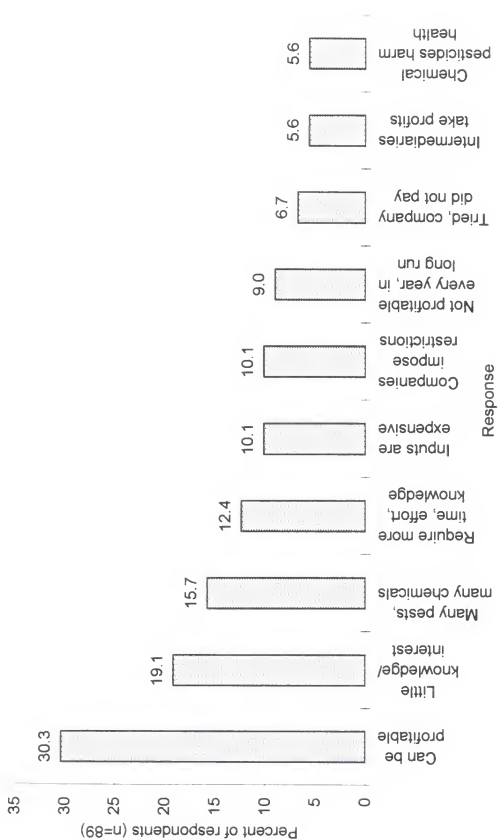


Figure 2-9. Responses to open-ended question of opinion of non-traditional crops, posed to farmers in two Sololá communities.



Farmers repeatedly stated during the interviews that they do not eat herbs from the broccoli fields because such herbs are laden with pesticides, although they do gather native herbs from the corn field to supplement the diet (Figure 2-10). Selective weeding, with the maintenance of useful herbs in the agroecosystem, has been documented for traditional farmers in southeastern Mexico (Chacón and Gliessman 1982). Many farm families in Sololá consume native greens several times a week and have a variety of medicinal uses for the herbs they collect (Table 2-1).

Table 2-1. Herbs commonly collected and utilized in the family diet by small-scale farmers in two Sololá communities.

| Plant family   | Scientific name                             | Common names                   |
|----------------|---------------------------------------------|--------------------------------|
| Amaranthaceae  | <i>Amaranthus hybridus</i> L.               | bledo, tzets, ses, huisquilete |
| Chenopodiaceae | <i>Chenopodium</i> sp.                      | apazote                        |
| Compositae     | <i>Bidens chiapensis</i> Brandg.            | shup                           |
|                | <i>Gallinsoga urticaefolia</i> (HBK) Benth  | macar, hoja nueva              |
|                | <i>Sonchus oleraceus</i> L.                 | curcur, lechugilla             |
| Cruciferae     | <i>Brassica</i> sp. (campestris or napa)    | napish, mostaza                |
|                | <i>B. integrifolia</i> (Willd.) Rupr.       | yerba blanca                   |
|                | <i>Nasturtium officinale</i> R. Br.         | berro, guixocul                |
| Fabaceae       | <i>Crotalaria longirostrata</i> Hook & Arm. | Chipilín, chop, tcap-in        |
|                | <i>Calandrinia micrantha</i> Schlecht.      | Barba de San Nicolás           |
| Portulacaceae  | <i>Solanum nigrescens</i> Mart & Gal        | Macuy, hierbamora, quilete     |

Finally, farmers were asked about their experience with and perception of intercropping, to evaluate possible reaction to more intensive cropping systems. Traditional intercrops help to meet the multiple objectives of small-scale farmers

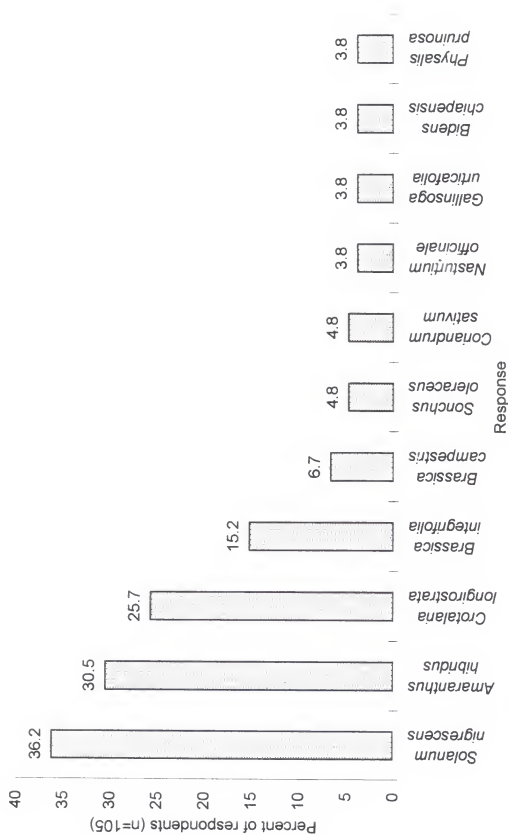


Figure 2-10. Responses to open-ended question of wild herbs collected, posed to farmers in two Sololá communities.

(Jodha 1980), and the cultivation of many native crops within traditional systems is practiced with intercrops (Nabhan 1992). One example is the Aztec and Mayan practice of intercropping corn and amaranth (*Amaranthus* spp.), still found in parts of Mexico (Williams and Brenner 1995).

Intercrops observed in the field or reported by interviewed farmers are given in Table 2-2. Seventy percent of those interviewed reported utilizing at least one type of intercrop, but for 71% of those, that intercrop was corn and beans. While 38.9% of those responding admitted success with at least 1 example other than corn and beans, many were negative about the practice, citing a lack of room between rows to work with the hoe, shading of some crops by others, and that the practice in general "does not work" (Figures 2-11 and 2-12). The responses to questions about intercropping suggest that any recommendations involving more intensive cropping systems than are currently practiced should be accompanied by thorough extension programs to avoid conflict with local perceptions of intensive systems. In the future, extension efforts could be coordinated with the numerous local organizations promoting organic agriculture in the region (Castañeda et al. 1994), whose success in spreading awareness was apparent during the study.

In ranking crops by preference, informants chose corn as the most preferred in both sites, followed by black beans (Table 2-3). Tomato, a crop many in San Andrés Semetebaj have expressed an interest in growing, was fifth in overall preference. Husk tomato (*Physalis pruinosa* L.), amaranth and other herbs appeared below most of the common crops, probably because traditional

Table 2-2. Intercrops utilized by farmers in two Sololá communities.

| Intercrops utilized by respondents          | Additional intercrops known by respondents |
|---------------------------------------------|--------------------------------------------|
| Corn + black bean (vine type)               | Corn + chili                               |
| Corn + black bean (bush type)               | Carrots + faba beans                       |
| Corn + black bean (vine type and bush type) | Carrots + cilantro                         |
| Corn + black bean + faba bean               | Radish + cilantro                          |
| Corn + black bean + chili + faba bean       |                                            |
| Corn + black bean + avocado                 |                                            |
| Corn + black bean + squash                  |                                            |
| Corn + faba bean + squash                   |                                            |
| Corn + tomato                               |                                            |
| Corn + faba bean                            |                                            |
| Corn + cilantro                             |                                            |
| Corn + piloy bean                           |                                            |
| Black bean + faba bean                      |                                            |
| Black bean + sweet potato                   |                                            |
| Black bean + tomato                         |                                            |
| Black bean + flowers                        |                                            |
| Faba bean + flowers                         |                                            |
| Tomato + cilantro                           |                                            |
| Broccoli + tomato                           |                                            |
| Carrots + <i>Brassica integrifolia</i>      |                                            |
| Potato + <i>Brassica integrifolia</i>       |                                            |
| Onion + <i>Brassica integrifolia</i>        |                                            |

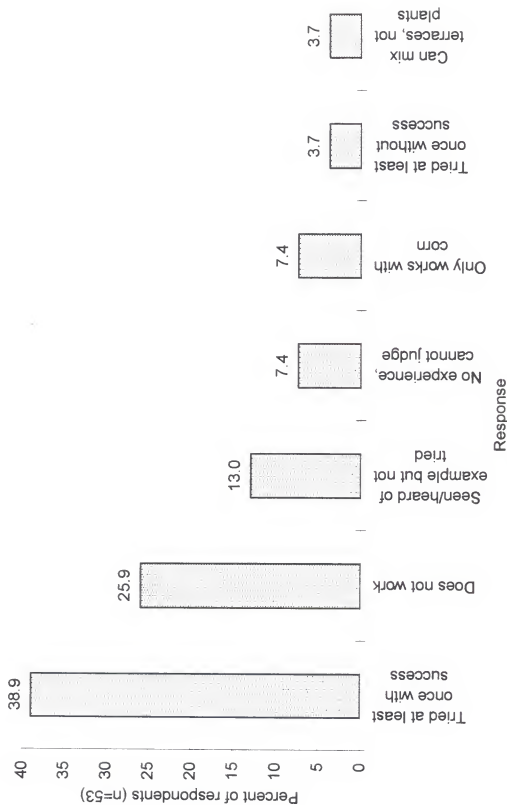


Figure 2-11. Responses to open-ended question of experience with intercropping beyond corn and beans, posed to farmers in two Sololá communities.

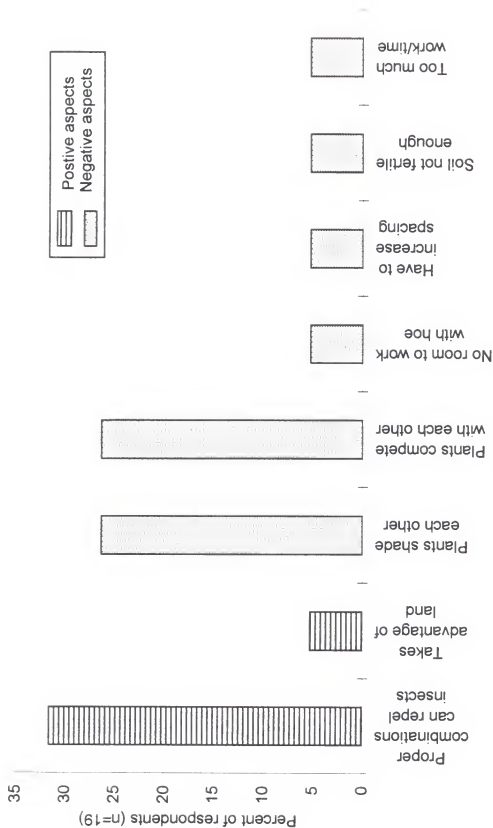


Figure 2-12. Responses to open-ended question of positive and negative aspects of intercropping, posed to farmers in two Sololá communities.

Table 2-3. Order of preference of 29 crops presented to farmers in two Sololá communities.

| Rank | Total<br>(n=50)     | San José<br>Chacayá<br>(n=27) | San Andrés<br>Semetebaj<br>(n=23) | Men<br>(n=25)       | Women<br>(n=25)     |
|------|---------------------|-------------------------------|-----------------------------------|---------------------|---------------------|
| 1    | Corn                | Corn                          | Corn                              | Corn                | Corn                |
| 2    | Black beans         | Black beans                   | Black beans                       | Black beans         | Black beans         |
| 3    | Potatoes            | Potatoes                      | Tomato                            | Potatoes            | Onion               |
| 4    | Onion               | Onion                         | Potatoes                          | Onion               | Potatoes            |
| 5    | Tomato              | Carrots                       | Onion                             | Green beans         | Tomato              |
| 6    | Carrots             | Green beans                   | Carrots                           | Carrots             | Carrots             |
| 7    | Green beans         | Tomato                        | Squash                            | Tomato              | Peppers             |
| 8    | Squash              | Squash                        | Faba beans                        | Squash              | Squash              |
| 9    | Faba beans          | Peas                          | Green beans                       | Peas                | Faba beans          |
| 10   | Peas                | Faba beans                    | Peppers                           | Piloy beans         | Green beans         |
| 11   | Piloy beans         | Radish                        | Piloy beans                       | Faba beans          | Peas                |
| 12   | Peppers             | Cabbage                       | Peas                              | Radish              | Piloy beans         |
| 13   | Radish              | Cauliflower                   | Radish                            | Cilantro            | Radish              |
| 14   | Cilantro            | Piloy beans                   | Cilantro                          | Cauliflower         | Cauliflower         |
| 15   | Cauliflower         | Peppers                       | Husk tomato                       | Cabbage             | Cilantro            |
| 16   | Husk tomato         | Cilantro                      | Flowers                           | Husk tomato         | Husk tomato         |
| 17   | Cabbage             | Husk tomato                   | Broccoli                          | Peppers             | Hierba mora         |
| 18   | Broccoli            | Beets                         | Hierba mora                       | Beets               | Cabbage             |
| 19   | Hierba mora         | Broccoli                      | Wheat                             | Broccoli            | Broccoli            |
| 20   | Flowers             | Hierba mora                   | Cauliflower                       | Chipilin            | Flowers             |
| 21   | Beets               | Chipilin                      | Chipilin                          | Snow peas           | Chipilin            |
| 22   | Chipilin            | Hierba blanca                 | Cabbage                           | Flowers             | Beets               |
| 23   | Strawberries        | Flowers                       | Beets                             | Hierba mora         | Amaranth            |
| 24   | Amaranth            | Snow peas                     | Strawberries                      | Strawberries        | Wheat               |
| 25   | Hierba<br>blanca    | Amaranth                      | Amaranth                          | Hierba blanca       | Strawberries        |
| 26   | Snow peas           | Strawberries                  | Snow peas                         | Brussels<br>sprouts | Hierba blanca       |
| 27   | Wheat               | Hoja de tamal                 | Hierba<br>blanca                  | Amaranth            | Hoja de tamal       |
| 28   | Hoja de<br>tamal    | Brussels<br>sprouts           | Hoja de<br>tamal                  | Wheat               | Snow peas           |
| 29   | Brussels<br>sprouts | Wheat                         | Brussels<br>sprouts               | Hoja de tamal       | Brussels<br>sprouts |

crops are often shown less respect culturally (CATIE 1979, Martínez and Alfaro et al. 1994). Additionally, since they are gathered in small quantities, they are sold in small quantities in local markets and are not considered to have high market potential. However, rising imports to the United States of such crops as husk tomato and cilantro (*Coriandrum sativum* L.) and a growing international market for amaranth may be exploited in the future (Bock et al. 1995, Can et al. 1991-92, Maynard 1993, Schnetzler and Breene 1994). Despite the high percentage of farmers growing broccoli, it resulted in being 18th of 29 crops. Although many farmers continue to grow broccoli, the problems they have had with the export companies and the high inputs required probably cause them to perceive the crop negatively. The snow pea was close to the bottom and brussels sprouts was last. These crops were among the first in the export trend in the study area, but failed to produce expected profits.

#### Principal Pests, Perceptions of Changing Pest Status, and Recognition of the Role of Beneficials

When asked about the history of agricultural pests in the area, 89.5 % of respondents stated that pest problems are greater now than in the past, with 10.5 % saying there is no difference, and none believing that pests were more of a problem in the past. Many respondents recognized that pests became problematic with the adoption of chemical fertilizers and pesticides, but as Bentley (1989b) found in Honduras, a lack of understanding of natural enemies has prompted the rise of alternative explanations. Fertilizer companies are said



to add insects to their products to increase dependence on chemical pesticides, and it is commonly recounted that several decades ago, planes dropped boxes of insects on the communities for the same reason (probably a reference to the sterile release screwworm eradication program active in Guatemala until recently) (Figure 2-13). Also, one person noted that nontraditional crops have more pests, and one described earlier practices involving organic matter amendments to the soil as inhibiting pest populations.

Farmer descriptions of the pests found on the major crops are summarized in Table 2-4. The most commonly cited pests were the white grub *Phyllophaga* spp. ("*gallina ciega*") and the leaf beetles *Microaltica mexicana* and *Diphaulaca wagneri* (referred to locally as "*timosus*"). In addition, the term "*argeño*" was used frequently to note a generalized poor growth of the plant, in some cases due to root pathogens and in others to unknown causes. Farmers' descriptions of insect pests were often extremely vague. While some farmers had learned genus and species names from export company agronomists (such as *Plutella*), most were only able to describe a pest as "a worm," "a bug," or "a little animal," and when questioned further were often unsure of color, time of occurrence, and distinguishing characteristics.

When farmers in the nearby community of Peña Blanca were later shown 20 specimens of insects common in agricultural crops in the area and asked to identify and describe their activities within the agroecosystem, they were able to name only a few of the insects. When describing what the insects do, they correctly identified the roles of 23.9% of them. Forty percent of the pest insects

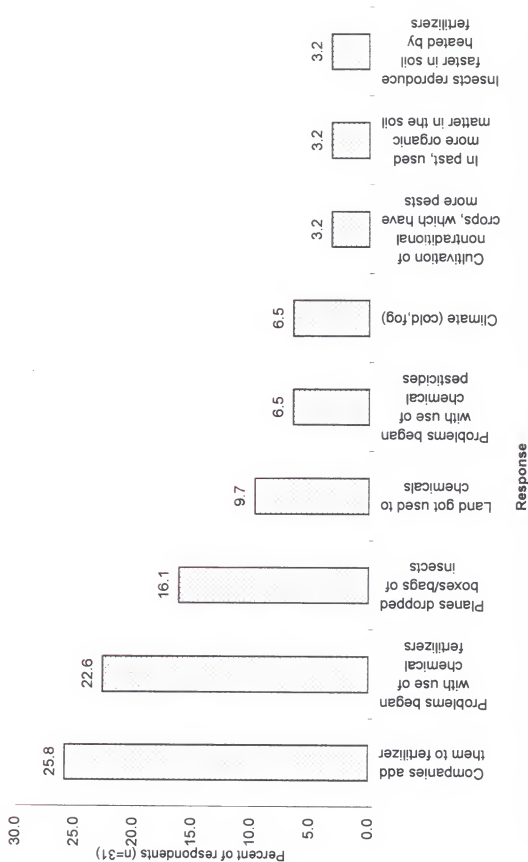


Figure 2-13. Responses to open-ended question of reasons for change in pest problems from past, posed to farmers in two Sololá communities.

Table 2-4. Principal pests reported by interviewed farmers.

| Crop        | Insects                                                                                                                            | Disease Pathogens                                                                                                                                        | Vertebrates            | Other invertebrates |
|-------------|------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------|---------------------|
| Corn        | <i>Phyllophaga</i> spp.<br><i>Spodoptera frugiperda</i><br>earworm<br>cutworms<br>stemborers<br>wireworms<br>earwigs<br>leafminers | <i>Fusarium</i> spp. (vascular wilt)<br><i>Alternaria bori</i>                                                                                           | rats<br>moles<br>birds |                     |
| Black beans | <i>Microaltica mexicana</i><br><i>Diphalauca wagneri</i><br>wireworms                                                              | <i>Fusarium</i> spp. (vascular wilt)<br><i>Uromyces phaseoli</i> (bean rust)                                                                             | moles                  | nematodes<br>slugs  |
| Broccoli    | <i>Plutella xylostella</i><br>leafminers<br>aphids<br>cutworms                                                                     | <i>Botrytis</i> sp.<br><i>Peronospora</i> (downy mildew)                                                                                                 | moles                  |                     |
| Faba beans  | aphids                                                                                                                             |                                                                                                                                                          |                        |                     |
| Potato      | <i>Phyllophaga</i> spp.<br>leafminers<br>wireworms<br>aphids                                                                       | <i>Alternaria solani</i> (early blight)<br><i>Phytophthora infestans</i> (late blight)<br><i>Xanthomonas</i> sp.<br><i>Fusarium</i> spp. (vascular wilt) |                        | slugs               |
| Tomato      | wireworms<br>cutworms<br>aphids                                                                                                    | <i>Alternaria solani</i> (early blight)<br><i>Phytophthora infestans</i> (late blight)                                                                   |                        |                     |

were correctly characterized as pests, while only 5% of beneficials were distinguished as such. Forty and 48% of pest and beneficial insects, respectively, were unknown to the farmers in terms of their role (Figure 2-14). Despite the inherent pest control characteristics of many traditional cropping systems, farmers are often unaware of the existence of beneficial insects (Altieri 1990a, 1984b, Altieri and Trujillo 1987).

When asked about the relative abundance of pests in intercrops versus monocultures, 64% of respondents explained that intercrops have more pests, and 29% felt that pests would be equally abundant. Of the former group, all regarded the more intensive intercrop as more attractive to pests, since more plant material was equated with more food for insects.

Most beneficials that were recognized as non-pest species were considered, at most, harmless (29% of total beneficials). In fact, few farmers could say that any insect is "good." The beneficial nature of some insects within agroecosystems was not within the conceptual framework of most farmers. Bentley (1989b) and Andrews et al. (1993) have described the perceptions of small-scale farmers in Honduras in much the same way, with clear gaps in knowledge of insects, particularly as related to insect reproduction and natural enemies, phenomena that are generally difficult to observe. As was true with the traditional Honduran farmers, insects for these small-scale Guatemalan farmers are primarily seen as herbivores that threaten their crops and must be destroyed before they take over. For example, farmers in Peña Blanca who have observed beneficial wasps taking nectar from crop flowers believed that the flower and

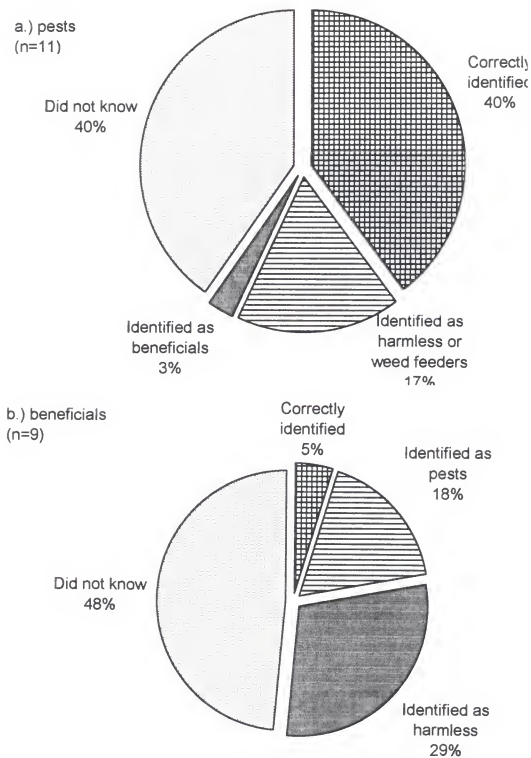


Figure 2-14. Mean percent of a.) pest and b.) beneficial insects identified by 19 informants according to their role in agroecosystems.

leaves of the plant subsequently dried out as a result. Such an attitude of all insects being the enemy has contributed to over-zealous spraying with pesticides in Central America, often without economic justification (Andrews et al. 1993).

#### Basis of Farmers' Agricultural Knowledge

When questioned about their major concerns, farmers most frequently mentioned the need for profitable crops (Figure 2-15). The high cost of inputs also was cited repeatedly, and while only 2 people were most concerned about the health effects of pesticides, such effects were cited as a minor concern several more times. The third most common concern was that of pests. With respect to the type of information farmers would be most interested in receiving, the most prevalent responses dealt with natural fertilizers and pesticides. Information about new crops as profitable alternatives and more effective pest control tactics were additional important concerns (Figure 2-16).

Interviews also included discussion of sources of technical advice, which was found to be received most often from the cooperative or export company agronomists (the primary source for 40.6% of those interviewed). These agronomists are said to visit the fields of every farmer contracted to grow broccoli, to advise on which pesticides to apply. Other sources of advice and information include training from parents, self experience, friends' and neighbors' advice, and agrochemical stores (Figure 2-17). Many farmers expressed distrust in extension workers, who are often said to give poor or

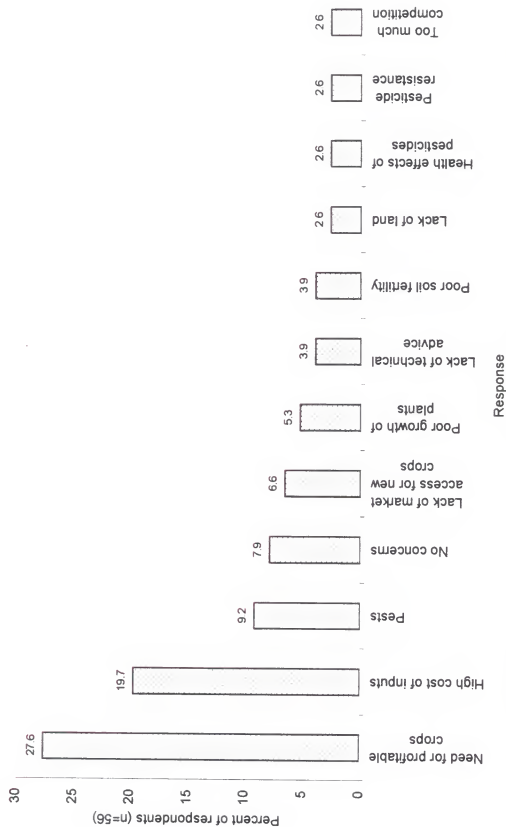


Figure 2-15. Responses to open-ended question of principal concern in agriculture, posed to farmers in two Sololá communities.

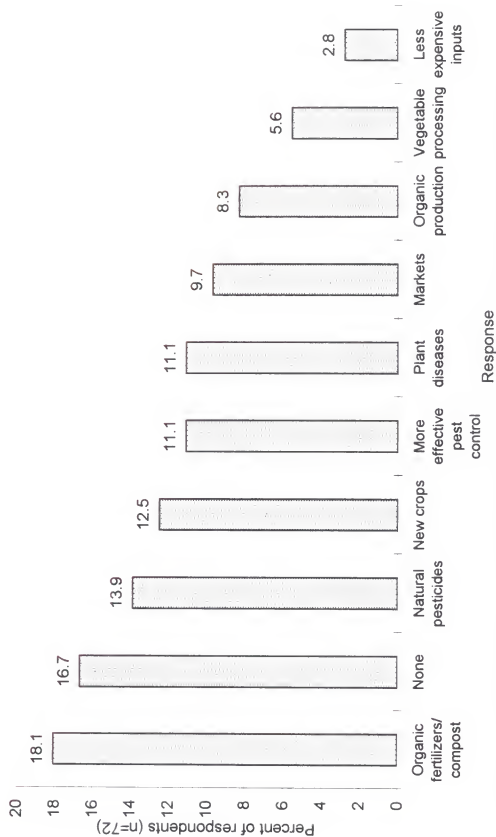


Figure 2-16. Responses to open-ended question of agricultural information desired, posed to farmers in two Sololá communities.



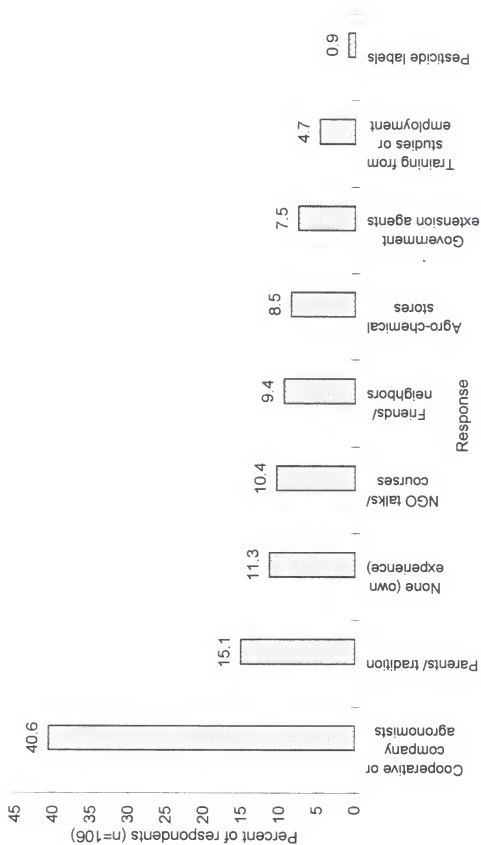


Figure 2-17. Responses to open-ended question of principal source of technical advice, posed to farmers in two Sololá communities.

inappropriate advice. In a study in Honduras, small-scale farmers also expressed doubt about the suggestions of extensionists, although continued contact with them also resulted in lower confidence in their own traditional agricultural knowledge (Bentley 1989a).

### Conclusions

The survey activities described here were designed to better understand farmer conditions, knowledge and attitudes. Increased profit, maintenance of traditions, and food security are some of the most important goals that cropping systems must satisfy to be appropriate for the farm families in the study area. Small-scale farmers in the region were found to be primarily constrained by land, capital, markets and the information base necessary to manage pests. Farmers were generally unaware of the role of natural enemies in the agroecosystem, and their incomplete knowledge of specific pest and beneficial insects highlights the lack of pest management information in their traditional agricultural knowledge base. In fact, most examples of effective traditional knowledge with respect to efficient use of natural resources in agriculture concentrate on soil and water management (Brush 1981, Mountjoy and Gliessman 1988, Wilken 1987).

Traditional agricultural knowledge must be taken into account when designing pest management strategies for small-scale tropical farmers (Thurston 1990, Altieri 1990b, Glass and Thurston 1978). However, where little more than cursory understanding of the ecological processes involved and little recognition

of key organisms exist, the traditional knowledge base cannot be relied upon. In this case, where chemical control of pests is prevalent and alternative sources of knowledge are rarely existent, the best strategy is to avoid the need for pest management as much as possible by choosing crops that minimize pest problems.

One of the most noteworthy results of the survey is the continued significance of corn and the desire to maintain certain traditional crops and practices, despite pressure to adopt high-cash crops and synthetic inputs. Corn, despite its low market price, remains a vital element in the culture, religion and diet of the Mayan groups in the region, and caring for the land and the revered corn plant is fundamental to the Mayan way of life (Rojas Lima 1988, Bukasov 1981, Johannessen 1982, Elbow 1974). Therefore, although alternative production systems are needed, corn and beans must remain the focus of any cropping systems tested, and secondary crops should be chosen for their role in minimizing pest problems, as well as the economic and nutritional benefits they provide. For an alternative cropping system to be economically, environmentally and culturally sustainable, it must be intermediate between the traditional corn and bean systems, which can no longer provide for the needs of the population, and an export vegetable monoculture, which can cause environmental and cultural damage without providing economic stability.

### CHAPTER 3

## INSECT PEST AND BENEFICIAL POPULATIONS, DISEASE AND DAMAGE IN CORN MONOCULTURE AND TWO ALTERNATIVE INTERCROPS

### Introduction

Agricultural research aimed at modernization of farmers in developing countries tends to overlook the ecological and socio-economic heterogeneity of traditional agricultural systems, concentrating on large-scale yield-improving technologies that are not appropriate for many small-scale farming systems (Altieri and Trujillo 1987, Francis et al. 1986). On the other hand, the design of site-specific cropping systems may contribute to the long-term success of agricultural development projects that aim to resolve the most pressing needs of small-scale farm families in the tropics. However, such systems must be designed carefully to avoid creating additional management problems. The design of more intensive cropping systems may or may not create undesirable consequences for the already difficult task of pest management faced by the small-scale farmer. Therefore, alternative cropping systems hypothesized to provide greater economic and health benefits to the farm family must be carefully scrutinized through field experiments in the immediate area for any resulting effects on pests.

The most immediate set of problems facing small-scale farmers in the western Guatemalan highlands are the need for income-generating crops, the threat to cultural traditions, and the misuse of synthetic chemical pesticides. Before cropping systems can be recommended as alternatives, these needs must be addressed. While the maintenance of corn in the cropping system is essential for the maintenance of cultural traditions, the increasing need for greater income can be met by adding cash crops to the system, as long as the yield of corn is not reduced. If this can be accomplished while at the same time reducing the pest numbers or apparent damage (or at least maintaining the same levels), the use of synthetic pesticides will not be increased. As a result, the alternative cropping system would be more appropriate to the needs of target farmers, and the likelihood of acceptance would be higher. Incorporating the needs and perceptions of the target group into research recommendations can increase the degree of acceptance of an agricultural innovation (Grieshop et al. 1988).

The choice of secondary crops incorporated into the system can have consequences for the natural control of corn insect pests, both directly as a result of ecological interactions and indirectly as a result of changes in chemical pesticide use on corn, or additional usage on secondary crops. Root (1973) developed the natural enemies hypothesis to suggest that reductions in herbivore abundance in vegetationally diverse habitats may be the consequence of greater favorability of more diverse habitats to natural enemies (alternative prey, nectar sources, microclimatic changes, etc.). The response of natural

enemies to habitat diversity has been studied with inconsistent results (for example, Brust et al. 1986, Coll and Bottrell 1996, Risch et al. 1982), and it is clear that the particular ecological conditions present in each case determine the response of natural enemy populations to diversity. For example, in an evaluation of traditional corn production systems in Tlaxcala, Mexico, Altieri and Trujillo (1987) concluded that fluctuations in both herbivore and predator densities depended on a number of factors, such as temporal and spatial crop arrangements, presence of non-crop vegetation in and around the field, and type of management.

However, the negative impact that chemical insecticides can have on natural enemies has been more consistently documented in many agroecosystems, including that of corn (Brust et al. 1986, Perfecto 1990, Garcia 1991). Therefore, it makes more sense to concentrate on intercrop combinations that will not only provide more economic and nutritional benefits than corn alone but also not require pest control. Such combinations would encourage natural control and at the same time account for the constraints of small-scale farmers.

Two alternative cropping systems designed to conform to the constraints and needs of small-scale farmers in Sololá, Guatemala, were examined in terms of insect pest and beneficial populations, disease and damage. The objective was to determine if the additional plants intercropped with corn would give rise to greater pest population densities, lower beneficial population densities, greater

disease presence, or greater damage, any of which would provoke the farmer to utilize greater amounts of synthetic pesticides.

Since economic return may outweigh potential changes in pest numbers, both a high-risk alternative, utilizing crops that have both greater economic potential and greater potential pest problems, and a low-risk alternative, including crops with lower potential pest problems and lower expected returns, were examined. The high-risk intercrop included black beans, broccoli and faba beans with the main crop corn. Faba beans are commonly grown in the area and are often grown around the house or within the cornfield. The crop has a stable local market, and its high protein and mineral content makes it nutritionally appealing (Rani and Hira 1993). However, farmers in the area related that yields have declined, and faba beans now experience greater pest attack, particularly from aphids. Broccoli is the principal export crop in the area, and while production for export markets may not be appropriate to the conditions of small-scale farmers, there is also a strong market in Guatemala City, and to some extent in Sololá.

The second alternative, the low-risk intercrop, was comprised of the main corn crop with the secondary crops black beans, amaranth (*Amaranthus cruentus*), and cilantro. *Amaranthus* spp. constituted an important food staple in pre-Columbian Aztec and Mayan civilizations, and amaranth-based products are now growing in popularity worldwide, with market expansion expected in the future. Amaranth seed has a high protein content, and many species and cultivars are resistant to drought, heat and pests (National Research Council

1984, Weber 1980, R. Bressani, Universidad del Valle, personal communication 1995).

Furthermore, amaranth has potential for reducing pest populations when intercropped with corn in a non- or low-chemical use pest management program. Tingle et al. (1978) collected larvae of the beet armyworm (*Spodoptera exigua* (Hubner)), the southern armyworm (*Spodoptera eridania* (Cramer)) and the beet webworm (*Herpetogramma bipunctalis* (F.)) from *A. hybridus* growing within field corn in Hastings, Florida. They reared from these larvae nine native parasite species, all of which were also parasites of the serious corn pest *Spodoptera frugiperda* (J.E. Smith) (fall armyworm), but no fall armyworm larvae were found feeding on the amaranth. In field tests in Honduras, *Spodoptera latifascia* (Walker) showed an oviposition preference for *Amaranthus* sp. over sorghum (*Sorghum bicolor* (L.) Moench) and various non-crop species, and equal to that of maize (Portillo et al. 1996). Therefore, amaranth may serve as a nursery crop for natural enemies of key corn pests.

Insect pests known to attack amaranth in the United States include principally the lygus bug (*Lygus* spp.), especially the tarnished plant bug (*L. lineolaris* Palisot de Beauvois), and the amaranth weevil (*Conotrachelus senialus* Leconte), with some reports of limited infestations by European corn borer (*Ostrinia nubilalis*), fall armyworm, cabbage looper (*Trichoplusia ni* (Hubner)) and corn earworm (*Helicoverpa zea* Boddie) (Weber 1980, Wilson and Olson 1990, Clark et al. 1995). However, information is not widely available pertaining to pests of amaranth in Guatemala.



Finally, although not native to the region, cilantro is a popular herb in Guatemala and Mexico, used for adding flavor to sauces, soups, vegetables, and other dishes. Its increasing popularity in the United States suggests that there is potential market growth. In addition, coriander seeds and oil extracts have been evaluated for their potential insect repellent properties (Su 1986). Several farmers in the study area reported the cilantro plant to be free of insects and occasionally plant it for its repellent effects.

The extent to which these alternative secondary crops may affect pest populations on, and damage to, the corn crop, particularly under the conditions of the study area, has not been evaluated. In fact, information on insects present in traditional Guatemalan agroecosystems is rare, with few exceptions (Painter 1955, Morales et al. 1993). This study therefore compares two alternative corn intercrops to corn in monoculture, in terms of pest and beneficial populations, and describes pest presence on secondary crops to determine the likelihood that either alternative will increase the use of synthetic chemical pesticides.

### Methods and Materials

Field plots were established at the Escuela de Formación Agrícola in Sololá, Guatemala at the start of the rainy season, 1996. The study site, on hilly land with an altitude of 2095 m, was chosen for its topographic and vegetational similarity to small farms in the area. Soils are sandy loam alfisols, with volcanic ash influence (66% sand, 22% silt, 12% clay). A pre-plant soil analysis of the

study fields showed soils to have a pH value of 5.6 and an organic matter content of 3.6%, and to be deficient in both nitrogen and potassium. Data from a weather station at the site revealed that total precipitation during the experiment (May to November 1996) was 1272.8 mm. Daily temperatures for this time ranged from 12.7 °C (mean minimum) to 20.6 °C (mean maximum), with the mean median temperature being 16.6 °C.

#### Experimental Design and Agronomic Management of Field Plots

The three treatments consisted of the following: 1.) corn in monoculture, 2.) corn planted with black beans and later broccoli and faba beans, and 3.) corn planted with black beans and later cilantro and amaranth. Plant arrangements for the intercrop treatments are shown in Figure 3-1.

The experimental design was a randomized complete block with 6 replicates. Based on availability of open land, 3 areas within the school were utilized for the experiment, separated by 250-500 m, with 2 blocks (replicates) within each area. Plots measuring 15 X 8 m were laid out along the contour within each of the 6 blocks (one block below the other in each area) and separated by at least 7 m. Plots were terraced, as is most sloping agricultural land in the area, with 2-3 terraces per plot, constructed with hoes, and rows were planted along the contour. Plots in all 3 areas were on southeast facing slopes.

Monthly cutting with a machete minimized vegetation in areas between plots. Neither irrigation nor pesticides were applied to plots during the season.

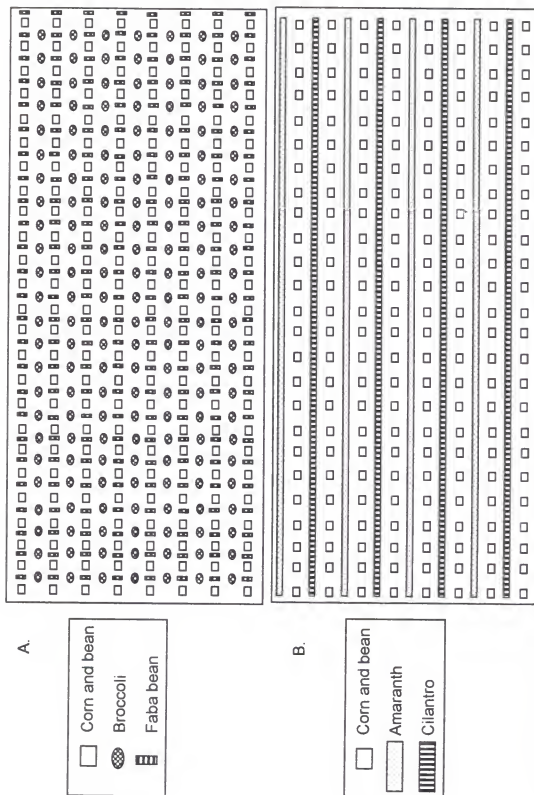


Figure 3-1. Plant arrangements in experimental plots of corn-based cropping systems, with treatments consisting of high-risk intercrop (A), low-risk intercrop (B) and monoculture, with corn planted at equal density.

Local farmers carried out all land preparation, planting, and weeding with hoes and machetes, and agronomic practices followed those of the region. Likewise, locally grown seed was used where possible.

On May 18, local yellow corn seed was planted in all plots at a distance of 0.6 m between plants and 1 m between rows. In plots of treatments 2 and 3, black bean seeds were planted together with the corn at a planting depth of approximately 10 cm. Diammonium phosphate (DAP) (18-46-0 NPK) at 100 kg/ha was applied to approximately 8 cm-diameter holes, 16,667 per ha, made with a machete. Four corn seeds and 3 bean seeds were placed in each hole, based on local resistance to planting fewer seeds per hole as a result of losses to birds and poor germination. A local corn variety in the highlands of Chiapas, Mexico, was found to have optimum yields at 4.6 seeds per hill (Márquez-Gómez et al.1992).

After covering the seeds with approximately 1 cm of soil, a hoe was used to create a mound behind the seeds to protect them from heavy rain. The following day, processed chicken manure (3-2-3 NPK) mixed with soil was applied in a furrow beside each mound at 841 kg/ha. At 3 weeks after planting, muriate of potash (0-0-60 NPK) and urea (46-0-0 NPK) were broadcast at 100 kg/ha in corn monoculture plots. Plots with intercrops received 150 kg/ha of each, divided in 2 applications, the first at the same time as the monoculture and the second a week later, after planting faba beans and cilantro in treatments 2 and 3 respectively. In addition, intercrops received 75 kg/ha of diammonium phosphate at planting. All plots received two more applications of urea (100 or

150 kg/ha for monoculture and intercrops respectively) at 9 and 13 weeks after planting, the last application coinciding with the first appearance of tasseling. Finally, soil test results showed a zinc deficiency, and so 2 applications of foliar zinc at 2 liters/ha were made to the corn and broccoli at 7 and 9 weeks after planting.

At 2 weeks after planting, corn was reseeded where poor germination, missing seeds, or scratched up seedlings from bird damage left empty mounds. Intercrops in treatments 2 and 3 were planted after the corn had germinated. Three weeks after planting, in all treatment 2 plots, 2 dried faba bean seeds from the local market were planted in each hole (16,000/ha), which had been dug with a hoe to approximately 8 cm, and to which 75 kg/ha of diammonium phosphate had been applied. Holes were dug along the row of corn, between corn mounds, and the distance between plants was 0.6 m. Faba beans were reseeded 2 weeks later and harvested on October 16, November 9 and December 2. Black beans were harvested on September 3 and solar dried.

On May 21, broccoli seeds obtained from a local agricultural store were planted in a seedbed to which 50 g/m<sup>2</sup> of 15-15-15 NPK fertilizer had been previously incorporated to approximately 30 cm, and 5 weeks later, seedlings were transplanted to treatment 2 plots. Broccoli seedlings were placed equidistantly between rows and between mounds of corn (Figure 3-1), at a distance of 0.6 m within the row, also with incorporation of 75 kg/ha of diammonium phosphate into the planting hole (14,000/ha). Plants that did not survive were replaced 2 weeks later. Further fertilization in treatment 2 plots is

described above, and broccoli was harvested on September 4, September 18 and October 16.

On June 12, locally obtained cilantro seed was planted in treatment 3 plots equidistantly between each row of corn at a spacing of 10 cm between plants, in 2 cm-diameter holes approximately 2 cm deep (100,000/ha), into which diammonium phosphate was incorporated at 75 kg/ha. Due to poor germination over all plots, cilantro was replanted 5 weeks later in two rows between every other row of corn (10 cm between plants and 20 cm between rows), with amaranth planted in 2 rows between the alternating rows of corn (15 cm between plants, 20 cm between rows, at 2 cm depth, 80,000/ha). Amaranth seed originated from the Rodale Institute (variety 84S-K277). Poor germination resulted in replanting of amaranth 3 and 6 weeks later. Cilantro was harvested on October 16 and November 25, and amaranth was harvested on December 6.

All plots were weeded with a machete and hoe at 4, 9, and 19 weeks after planting. At 6 and 9 weeks after planting, following local custom, soil was pulled up against each group of corn plants with a hoe, creating a mound that gave the plants greater support. Nevertheless, strong winds in August and height of corn plants contributed to lodging of corn in all plots. Lodged plants with no potential for ear development were removed on August 29. At the same time, some lower leaves of all corn plants were removed to prevent further lodging by relieving weight on the plants and allowing an outlet for the wind, further lessening pressure on the plants. By October, ears on lodged plants were receiving considerable damage from rodents and were sampled and removed on October

23 for sale as fresh ears. Remaining ears were turned down 3 weeks later to facilitate drying. This procedure ("*doblado*") is commonly practiced throughout Latin America by small-scale corn producers and has been documented frequently among Mayan farmers (Thurston 1992). In one study in Guatemala, 1% of grain from ears that had been bent down experienced fungal damage, compared to 14.5% from ears not bent down (Montoya et al. 1970). Finally, corn was harvested by hand on November 25 and further dried in the sun.

#### Insect, Disease and Damage Samples: Visual Observations

At weeks 3-5, 7-11, 13-15, and 18-19, plants were sampled non-destructively by visual observation. The sample unit was a 0.6-m length of cornrow, centered on a corn mound. Between 1 and 4 corn plants (seasonal mean of 3.47 corn plants per mound) and 1-2 bean plants were present in each sample unit. Number of units sampled per sampling date varied between 3 and 12, depending on height of corn plants and subsequent time needed for sampling. Within each plot, sample units were allocated systematically with a random start. On each sampling date, all visible parts of plants were examined, with numbers of insects and presence of disease and damage recorded.

#### Insect, Disease and Damage Samples: Destructive Plant Samples

At 2, 6, 12, 17, 22, 24 and 26 weeks after planting, corn plants were sampled destructively with the sampling unit and allocation described above. After cutting plants at 10 cm above the soil level and removing them from the

plots, all parts of each plant were thoroughly examined for insects and disease. During the last four destructive samples, damage to each corn ear was also recorded by source.

### Soil Samples

A pre-plant sample was taken for soil insects, in which 9 samples were taken per plot, allocated systematically with a random start. Blocks of soil 20 cm X 20 cm X 15 cm deep were removed with a machete, placed in plastic bags, stored at approximately 6<sup>0</sup> C and processed within 72 hours. Soil was placed in a kitchen strainer and water passed through, with the debris observed carefully for insects.

Soil samples were also taken at each destructive sample to determine significance of root-feeding insects. For each, a 20 cm X 20 cm X 15 cm deep block of soil, centered on the corn roots, was removed with a machete, placed in a plastic bag, stored at approximately 6<sup>0</sup> C and processed within 48 hours. Soil was placed in a shallow plastic pan and visually searched for insects.

### Samples of Corn Ear Development and Damage

Damage to corn ears was also measured at final grain harvest. Plants from 10 sample units per plot were inspected for number of ears, length and weight of ears (with moisture readings from a Dole Model 400B grain moisture tester used to adjust weights to 15% moisture), number of kernels and number of damaged kernels by origin of damage.



### Samples of Community Composition

In addition to quantitative evaluations of population densities, insects present in each of the cropping systems were monitored throughout the experiment, both through collections made during the sampling procedures previously described and through traps set out in the plots. Pitfall traps were left in each plot 14 times throughout the experiment to ascertain the presence of ground-dwelling insects. Four 10-ounce plastic drinking cups were buried to ground level in each plot, with 1-2 centered on each terrace. Each cup was filled with 50 ml of a 50:50 solution of antifreeze and water and emptied after 72 hours.

Baits for wireworms (Elateridae) were set out once, early in the season. Oatmeal and corn flake mixtures and rolled oats have been shown to be more attractive to wireworm larvae than other bait combinations (Jansson et al. 1989). A 50:50 mixture of corn seed and oatmeal (approximately 450g per bait) was therefore buried and covered with black plastic in 2 places in each plot 3 weeks after corn was planted. Insects were collected from the bait after 10 days.

Sticky traps with a yellow cardboard base were set out in all plots 4 times during the first half of the experiment. Two traps per plot were left for 72 hours each time, after which insects were removed. Use of sticky traps was not continued because of difficulty in removing insects and lack of time. One nocturnal sample was made 8 weeks after planting corn, in which 4 people visually searched foliage and ground in all treatments from 20:30 to 22:30 hours,

0:30 to 2:00 hours and 4:00 to 6:30 hours. Insects were collected for later identification.

Finally, immature insects collected during sampling were reared both to obtain adult specimens for identification and to determine presence of parasitoids. Rearing was carried out in individual plastic containers, with host plant foliage replaced daily. Insects collected and reared were identified to genus or species utilizing the collections of the Universidad del Valle de Guatemala and the Florida State Collection of Arthropods. Samples of diseased tissues of all crops were collected during the experiment and analyzed by plant pathologists at the Universidad del Valle de Guatemala and a private phytopathology laboratory in Guatemala City (Agri-Lab).

### Statistical Analysis

Analysis of Variance was performed on insect densities, disease and damage incidence (percent of ears or plants infested), and ear and kernel development and damage estimates, after transformation to normalize the data (counts transformed by  $\log_{10}(x + 1)$  and percentages transformed by square root), using the PROC GLM procedure of SAS (SAS Institute 1990). The Student-Newman-Keuls test was used to separate means when significant treatment differences were detected ( $\alpha=0.05$ ). Although transformed data were used to determine treatment differences, means reported in tables are untransformed. For insect counts and percent of plants diseased or damaged, data were analyzed by sampling date and pooled to give seasonal means.

## Results and Discussion

### Insect Pest Populations on Corn

Herbivorous insects collected occasionally on corn and secondary crops are given in Table 3-1. Of those pests not quantified, the potentially most serious are the grain weevils *Sitophilus zeamais* Motsch, which was not collected in the field but in stored corn grain, and *S. granarius*, as well as *Euxesta* sp., which was found on corn ears in low density. *E. stigmatis* Loew (the corn-silk fly) can cause high economic losses in Florida sweet corn (Seal and Jansson 1989), and several species of *Euxesta* have been reported to be major pests of field corn in Guatemala (Painter 1955). Only two larvae of *Diatraea* sp. were encountered during the entire season, although this stem borer is a major corn pest in the region (CATIE 1990a).

One of the most serious pests of corn in Central America, and perhaps the most studied, is the fall armyworm (*Spodoptera frugiperda* (J.E. Smith)) (Andrews 1980, 1988, Hruska and Gould 1997, Portillo et al. 1991, Cortez and Trujillo 1994). Andrews (1988) cites several examples of corn having lower damage by *S. frugiperda* when planted in polyculture than in monoculture. Altieri (1980) found the same results for corn-weed associations that included *Amaranthus* sp. Likewise, in a comparison of traditional corn production in monoculture, traditional corn intercropped with beans, and hybrid corn, Cortez and Trujillo (1994) observed lower larval populations in the polyculture. Additionally, there was a 10-fold increase in larval populations of *S. frugiperda* in

Table 3-1. Insect herbivores collected in corn-based cropping systems.

| Order     | Family       | Sub-family, genus or species          | Crop                            |
|-----------|--------------|---------------------------------------|---------------------------------|
| Hemiptera |              |                                       |                                 |
|           | Miridae      | <i>Collaria oleosa</i> (Distant)      | Corn                            |
|           |              | <i>Creontiades rubrinervis</i> (Stal) | Corn                            |
|           |              | <i>Lygus</i> sp.                      | Corn                            |
|           | Lygaeidae    | <i>Lygaeus belfragei</i> Stal         | Corn                            |
|           |              | <i>Xyonysius</i> sp.                  | Corn                            |
|           | Largidae     | <i>Largus cinctus</i> (H.-S.)         | Corn                            |
|           | Alydidae     | <i>Alydus</i> sp.                     | Amaranth                        |
|           | Pentatomidae | <i>Paddeus irroratus</i> (H.-S.)      | Corn, faba bean                 |
|           |              | <i>Acrosternum</i> sp.                | Corn, faba bean, amaranth       |
|           |              | <i>Murgantia histrionica</i> (Hahn)   | Broccoli, husk tomato, amaranth |
| Homoptera |              |                                       |                                 |
|           | Membracidae  | <i>Antianthe</i> sp.                  | Corn                            |
|           |              | <i>Polyglypta</i> sp.                 | Corn                            |
|           |              | <i>Stictocephala lutea</i> (Walker)   | Corn, beans                     |
|           | Cercopidae   | <i>Tomaspis</i> sp.                   | Corn                            |
|           |              | <i>Prosapia bicincta</i> (Say)        | Corn                            |
|           |              | <i>Clastoptera obtusa</i> (Say)       | Corn                            |
|           |              | <i>Clastoptera</i> sp. 2              | Corn                            |
|           |              | <i>Clastoptera</i> sp. 3              | Corn                            |
|           | Cicadellidae | <i>Graphocephala</i> sp. 1            | Amaranth                        |
|           |              | <i>Graphocephala</i> sp. 2            | Amaranth                        |
|           |              | <i>Graphocephala</i> sp. 3            | Amaranth                        |
|           |              | <i>Draeculacephala</i> sp.            | Corn                            |
|           |              | <i>Empoasca</i> sp.                   | Beans                           |
|           |              | <i>Osbornellus</i> sp.                | Corn                            |
|           |              | <i>Scaphytopius</i> sp.               | Corn                            |
|           |              | <i>Macrosteles</i> sp.                | Corn                            |
|           | Derbidae     | <i>Anotia</i> sp.                     | Corn                            |
|           | Aphidae      | <i>Aphis craccivora</i>               | Beans                           |
|           |              | <i>A. gossypii</i>                    | Corn, beans                     |
|           |              | <i>Acyrtosiphon pisum</i> (Harris)    | Beans                           |
|           |              | <i>Brevicoryne brassicae</i> L.       | Broccoli                        |
|           |              | <i>Histioneura sitariae</i> (Thomas)  |                                 |
|           |              | <i>Macrosiphum</i> sp.                |                                 |
|           |              | <i>M. euphorbiae</i>                  | Faba bean, amaranth             |
|           |              | <i>Metopolophium dirhodum</i>         | Corn                            |
|           |              | Walker                                |                                 |
|           |              | <i>Myzus persicae</i> (Sulzer)        | Corn                            |
|           |              | <i>Rhopalosiphum insertum</i>         | Corn                            |
|           |              | (Walker)                              |                                 |
|           |              | <i>Rhopalosiphum maidis</i> (Fitch)   | Corn                            |

Table 3-1—Continued.

| Order      | Family         | Sub-family, genus or species              | Crop                       |
|------------|----------------|-------------------------------------------|----------------------------|
| Homoptera  | Aphidae        | <i>R. padi</i> L.                         | Corn, faba bean            |
|            |                | <i>R. rufiabdominalis</i> (Sasaki)        | Corn                       |
|            |                | <i>Sitobion avenae</i> (Fabricius)        | Corn                       |
|            |                | <i>Tetraneura nigriabdominalis</i> Sasaki | Corn                       |
|            |                | <i>Uroleucon</i> sp.                      | Amaranth                   |
| Coleoptera | Elateridae     | <i>Glyphonyx</i> sp.                      | Corn, beans                |
|            | Nitidulidae    | <i>Colopterus</i> sp.                     | Corn                       |
|            | Coccinellidae  | <i>Epilachna mexicana</i> (Guerin)        | Corn                       |
|            | Meloidae       | <i>Lytta eucesa</i> (Chevr.)              | Corn                       |
|            | Chysomelidae   | <i>Microaltica mexicana</i> (Chevr.)      | Corn, beans, faba beans    |
|            |                | <i>Disonycha</i> sp. 1                    | Corn                       |
|            |                | <i>Disonycha</i> sp. 2                    | Corn                       |
|            |                | <i>Disonycha</i> sp. 3                    | Amaranth, beans            |
|            |                | <i>Colaspis prosina</i> LeFevre           | Corn                       |
|            |                | <i>Chalcophana</i> sp.                    | Corn                       |
|            |                | <i>Diphalaucia wagneri</i>                | Corn, beans, broccoli      |
|            |                | <i>Diabrotica balteata</i> Lec.           | Corn                       |
|            |                | <i>D. nigrolineata</i>                    | Corn                       |
|            |                | <i>D. porracea</i> (Harold)               | Corn, broccoli, faba beans |
|            |                | <i>Acalymma vittata</i> (Fabricius)       | Corn, beans                |
|            |                | <i>A. innuba</i> (Fabricius)              | Corn                       |
|            |                | <i>Gyandrobrotica lepida</i>              | Beans                      |
|            |                | <i>Cerotoma atrofasciata</i> Jacoby       | Corn, beans, broccoli      |
|            |                | <i>Cryptocephalus</i> sp.                 | Amaranth                   |
|            |                | <i>Chaetocnema</i> sp. 1                  | Corn, amaranth             |
|            |                | <i>Chaetocnema</i> sp. 2                  | Corn, faba bean            |
|            |                | <i>Brachypnoea</i> sp.                    | Corn, broccoli             |
|            | Apionidae      | <i>Apion</i> sp.                          | Corn, beans                |
|            | Curculionidae  | <i>Geraeus</i> sp. 1                      | Corn                       |
|            |                | <i>Geraeus</i> sp. 2                      | Corn                       |
|            |                | <i>Sitophilus granarius</i> (L.)          | Corn                       |
|            |                | <i>S. zeamais</i> Motsch.                 | Stored corn seed           |
| Diptera    | Otitidae       | <i>Euxesta</i> sp.                        | Corn                       |
|            | Playstomatidae | <i>Rivellia</i> sp.                       | Corn                       |
|            | Agromyzidae    | <i>Liriomyza commelinae</i>               | Corn                       |
|            |                | <i>Liriomyza</i> species                  | Corn, amaranth             |
|            |                | <i>Agromyza</i> sp.                       | Corn                       |

Table 3-1—Continued.

| Order       | Family      | Sub-family, genus or species              | Crop        |
|-------------|-------------|-------------------------------------------|-------------|
| Lepidoptera |             |                                           |             |
|             | Gelechiidae | <i>Sitotroga cerealella</i> (Oliver)      | Stored corn |
|             | Tortricidae | <i>Choristoneura</i> sp. 1                | Corn        |
|             |             | <i>Choristoneura</i> sp. 2                | Corn        |
|             | Pyralidae   | <i>Diatraea</i> sp.                       | Corn        |
|             |             | <i>Evergestis nimosalis</i> (Guen)        | broccoli    |
|             | Hesperiidae | <i>Perichares phytos</i>                  | Corn        |
|             |             | <i>Astrapes anaphes</i>                   | Beans       |
|             |             | <i>Urbanus proteus</i> (L.)               | Beans       |
|             | Pieridae    | <i>Leptophobia anipa</i> (Boisd.)         | Broccoli    |
|             | Arctiidae   | <i>Halisidota meridionalis</i>            | Faba beans  |
|             |             | <i>Halisidota</i> sp.                     | Corn        |
|             |             | <i>Melese amastris</i>                    | Corn        |
|             | Noctuidae   | <i>Estigmene acrea</i> (Drury)            | Corn, beans |
|             |             | <i>Lichneptera decora</i>                 | Corn        |
|             |             | <i>Eurois</i> sp.                         | Faba bean   |
|             |             | <i>Dargida procinctus</i>                 | Corn        |
|             |             | <i>Spodoptera frugiperda</i> (J.E. Smith) | Corn        |
|             |             | <i>Spodoptera</i> sp.                     | Corn        |
|             |             | <i>Agrotis subterranea</i> (Fabricius)    | Corn        |
|             |             | <i>Helicoverpa zea</i> (Boddie)           | Corn        |

"technologically improved" corn that involved a package of hybrid seed and chemical inputs. In the current study, population densities of *S. frugiperda* were no different in all cropping system treatments on all but one sampling date (9 weeks after planting), when the high-risk intercrop (corn with black beans, faba beans and broccoli) had a higher fall armyworm density than the monoculture. However, the seasonal mean density of *S. frugiperda* was higher in the monoculture than in the high-risk treatment. This was the only observed difference among treatments in seasonal mean densities of key insect pests on corn, although differences were observed for some insects on individual sampling dates (Tables 3-2 and 3-3). Overall, densities of key pests on corn remained low throughout the season.

There were a number of aphid species on corn throughout the experiment, the most abundant being the corn leaf aphid, *Rhopalosiphum maidis* (Fitch). As seen for the densities of fall armyworm, aphid populations were higher on corn in the high-risk intercrop for only one sampling date (26 weeks after planting), although there was no difference in the seasonal mean density. A higher population density on the high-risk intercrop was also seen for *Brachyphoea* sp. adults on one sampling date (17 weeks after planting), and again seasonal mean densities did not differ by cropping system.

Differences on some sampling dates were also seen for the densities of all leafhoppers. Two dates had greater density in the monoculture and one date had greater density in the high-risk treatment, although seasonal means were not different. Density of leafmines from *Liriomyza commelinae* (Frost), *Liriomyza*

Table 3-2. Densities (mean no. per 0.6 m-row corn  $\pm$  SEM) of insects on corn in monoculture, intercropped with black beans, faba beans and broccoli (high-risk), and intercropped with black beans, amaranth and cilantro (low-risk), for sampling dates where significant differences were detected.

| Where significant differences were detected. |      |         |      |         |         |       |      |         |      |   |      |    |
|----------------------------------------------|------|---------|------|---------|---------|-------|------|---------|------|---|------|----|
| <i>Spodoptera frugiperda</i>                 |      |         |      | Week 9  |         |       |      |         |      |   |      |    |
| Monoculture                                  |      |         |      | 0.00    | ±       | 0.00  |      | b       |      |   |      |    |
| High-risk intercrop                          |      |         |      | 0.14    | ±       | 0.06  |      | a       |      |   |      |    |
| Low-risk intercrop                           |      |         |      | 0.06    | ±       | 0.04  |      | ab      |      |   |      |    |
| Aphids                                       |      |         |      | Week 26 |         |       |      |         |      |   |      |    |
| Monoculture                                  |      |         |      | 1.33    | ±       | 1.33  |      | b       |      |   |      |    |
| High-risk intercrop                          |      |         |      | 28.83   | ±       | 19.68 |      | a       |      |   |      |    |
| Low-risk intercrop                           |      |         |      | 0.28    | ±       | 0.28  |      | b       |      |   |      |    |
| Leafhoppers                                  |      | Week 5  |      |         | Week 17 |       |      | Week 18 |      |   |      |    |
| Monoculture                                  | 0.72 | ±       | 0.22 | a       | 0.21    | ±     | 0.13 | ab      | 0.94 | ± | 0.42 | a  |
| High-risk intercrop                          | 0.18 | ±       | 0.06 | b       | 0.00    | ±     | 0.00 | b       | 0.33 | ± | 0.14 | ab |
| Low-risk intercrop                           | 0.18 | ±       | 0.06 | b       | 0.71    | ±     | 0.38 | a       | 0.00 | ± | 0.00 | b  |
| Leafmines                                    |      | Week 11 |      |         |         |       |      |         |      |   |      |    |
| Monoculture                                  |      |         |      | 0.42    | ±       | 0.08  |      | a       |      |   |      |    |
| High-risk intercrop                          |      |         |      | 0.36    | ±       | 0.11  |      | a       |      |   |      |    |
| Low-risk intercrop                           |      |         |      | 0.08    | ±       | 0.05  |      | b       |      |   |      |    |
| <i>Brachypnoea</i> sp.                       |      | Week 17 |      |         |         |       |      |         |      |   |      |    |
| Monoculture                                  |      |         |      | 0.00    | ±       | 0.00  |      | b       |      |   |      |    |
| High-risk intercrop                          |      |         |      | 0.17    | ±       | 0.08  |      | a       |      |   |      |    |
| Low-risk intercrop                           |      |         |      | 0.00    | ±       | 0.00  |      | b       |      |   |      |    |
| <i>Diphalauca wagneri</i>                    |      | Week 4  |      |         | Week 5  |       |      | Week 8  |      |   |      |    |
| Monoculture                                  | 0.03 | ±       | 0.02 | b       | 0.00    | ±     | 0.00 | b       | 0.00 | ± | 0.00 | b  |
| High-risk intercrop                          | 0.37 | ±       | 0.10 | a       | 0.18    | ±     | 0.06 | a       | 0.13 | ± | 0.06 | a  |
| Low-risk intercrop                           | 0.10 | ±       | 0.10 | b       | 0.00    | ±     | 0.00 | b       | 0.03 | ± | 0.02 | ab |

Treatment means followed by the same letter are not significantly different at  $\alpha=0.05$  ( $n=6$ , ANOVA and Student-Newman-Keuls test performed on data transformed by  $\log_{10}(x+1)$ ).



Table 3-3. Seasonal mean densities of key insect pests (no. per 0.6 m-row corn  $\pm$  SEM) on corn in monoculture, intercropped with black beans, faba beans and broccoli (high-risk intercrop), and intercropped with black beans, cilantro and amaranth (low-risk intercrop), during the rainy season of 1996.

|                                   | <i>Spodoptera frugiperda</i> |  | aphids              |  | leafhoppers         |  | <i>Liriomyza</i> spp. and<br><i>Agromyza</i> sp. mines |  |
|-----------------------------------|------------------------------|--|---------------------|--|---------------------|--|--------------------------------------------------------|--|
|                                   | Mean $\pm$ SEM               |  | Mean $\pm$ SEM      |  | Mean $\pm$ SEM      |  | Mean $\pm$ SEM                                         |  |
| <i>Helicoverpa zea</i>            |                              |  |                     |  |                     |  |                                                        |  |
| larvae                            |                              |  |                     |  |                     |  |                                                        |  |
| Corn monoculture                  | 0.201 $\pm$ 0.045 a          |  | 3.173 $\pm$ 0.327 a |  | 0.379 $\pm$ 0.034 a |  | 0.098 $\pm$ 0.014 a                                    |  |
| High-risk intercrop               | 0.082 $\pm$ 0.014 b          |  | 4.475 $\pm$ 0.675 a |  | 0.345 $\pm$ 0.032 a |  | 0.082 $\pm$ 0.013 a                                    |  |
| Low-risk intercrop                | 0.160 $\pm$ 0.043 ab         |  | 4.246 $\pm$ 1.108 a |  | 0.324 $\pm$ 0.036 a |  | 0.077 $\pm$ 0.012 a                                    |  |
| <i>Diabrotica porracea</i>        |                              |  |                     |  |                     |  |                                                        |  |
| adults                            |                              |  |                     |  |                     |  |                                                        |  |
| <i>Diaphalauca wagneri</i>        |                              |  |                     |  |                     |  |                                                        |  |
| Corn monoculture                  | 0.029 $\pm$ 0.009 a          |  | 0.044 $\pm$ 0.010 a |  | 0.005 $\pm$ 0.003 a |  | 0.045 $\pm$ 0.009 a                                    |  |
| High-risk intercrop               | 0.011 $\pm$ 0.005 a          |  | 0.047 $\pm$ 0.010 a |  | 0.071 $\pm$ 0.012 a |  | 0.030 $\pm$ 0.007 a                                    |  |
| Low-risk intercrop                | 0.018 $\pm$ 0.006 a          |  | 0.033 $\pm$ 0.009 a |  | 0.024 $\pm$ 0.009 a |  | 0.035 $\pm$ 0.007 a                                    |  |
| <i>Phyllophaga</i> sp.            |                              |  |                     |  |                     |  |                                                        |  |
| eggs and larvae                   |                              |  |                     |  |                     |  |                                                        |  |
| <i>Brachynema</i> sp.             |                              |  |                     |  |                     |  |                                                        |  |
| adults                            |                              |  |                     |  |                     |  |                                                        |  |
| Corn monoculture                  | 0.039 $\pm$ 0.007 a          |  | 0.057 $\pm$ 0.009 a |  | 0.009 $\pm$ 0.003 a |  | 0.111 $\pm$ 0.024 a                                    |  |
| High-risk intercrop               | 0.054 $\pm$ 0.011 a          |  | 0.034 $\pm$ 0.008 a |  | 0.015 $\pm$ 0.004 a |  | 0.137 $\pm$ 0.027 a                                    |  |
| Low-risk intercrop                | 0.034 $\pm$ 0.008 a          |  | 0.037 $\pm$ 0.007 a |  | 0.008 $\pm$ 0.004 a |  | 0.100 $\pm$ 0.024 a                                    |  |
| <i>Diabrotica porracea</i> larvae |                              |  |                     |  |                     |  |                                                        |  |
| Mean $\pm$ SEM                    |                              |  |                     |  |                     |  |                                                        |  |
| Corn monoculture                  | 0.019 $\pm$ 0.010 a          |  |                     |  |                     |  |                                                        |  |
| High-risk intercrop               | 0.015 $\pm$ 0.009 a          |  |                     |  |                     |  |                                                        |  |
| Low-risk intercrop                | 0.033 $\pm$ 0.014 a          |  |                     |  |                     |  |                                                        |  |

Treatment means followed by the same letter are not significantly different ( $\alpha=0.05$ ,  $n=120$ , ANOVA and Student-Newman-Keuls test performed on data transformed by  $\log_{10}(x+1)$ ).

sp. and *Agromyza* sp. were also higher in corn monoculture on one sampling date (11 weeks after planting), while no differences in seasonal means were detected. The usual host for *L. commelinae* is *Commelinae* spp., with reports from *Tradescantia* spp., both in the family Commelinaceae (Spencer 1983).

The only other differences in insect pest population densities were seen for *D. wagneri* adults, which were consistently present in greater density on corn in the high-risk treatment (Figure 3-2), although seasonal mean densities were not different. This chrysomelid, whose density was very low in corn monoculture, was abundant on bean plants, its usual host, in the intercrop treatments and was therefore probably not using corn as a host. Higher densities of *D. wagneri* on corn in the high-risk treatment are probably the result of higher populations observed on black beans in that treatment.

The population densities of other insect pests sampled on corn foliage and ears (*H. zea* larvae, *Collana oleosa* (Distant) adults, *Diabrotica porracea* (Harold) adults, *Geraeus* sp. adults and *Chaetocnema* sp. adults) were not influenced by cropping system, either on individual sampling dates or over the season as a whole. The polyphagous and mobile *Helicoverpa* spp. have been found in some cases to be more abundant in diverse cropping systems (Fitt 1989), but no such effect was seen here. *C. oleosa* has been reported to be present on corn in Guatemala with no detectable damage. However, *Diabrotica* and related chrysomelids were considered among the major pests in corn (Painter 1955), although in the current study their numbers were consistently low.

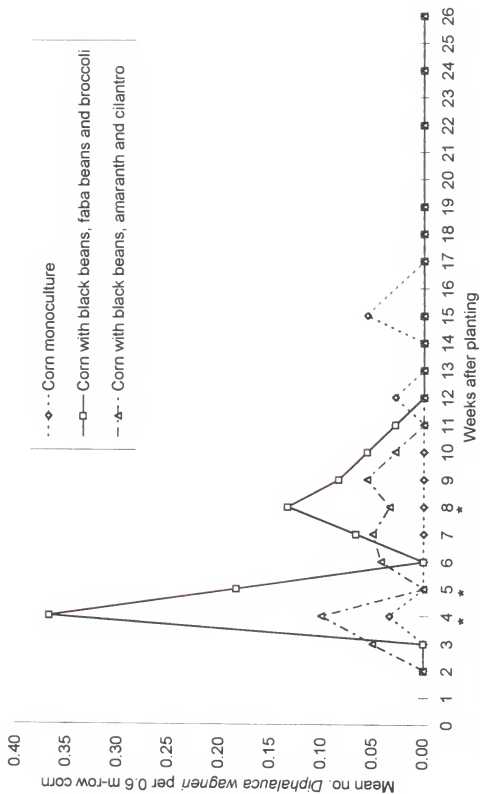


Figure 3-2. Mean densities of *Diphalauga wagneri* adults from corn in monoculture, corn intercropped with black beans, faba beans and broccoli, and corn intercropped with black beans, amaranth and cilantro, during the rainy season of 1996. Asterisks by sampling dates indicate significant treatment differences ( $\alpha=0.05$ ,  $n=6$ , ANOVA and Student-Newman-Keuls test performed on data transformed by  $\log(x+1)$ ).

No differences among treatments were detected for the densities of the 2 insect pests of corn found in soil samples, *Phyllophaga* sp. white grubs and *D. porracea* larvae. *Phyllophaga* spp. are important crop pests in Central America, especially on corn and sorghum (King 1984) and were cited as a major pest problem by farmers interviewed in the study area. More *Phyllophaga* spp. larvae were found in Costa Rica on ridged corn and on corn to which phosphate fertilizer had been added to an acid soil (King 1985). Although these conditions were present in the current study, populations of *Phyllophaga* sp. eggs and larvae in proximity to corn roots were low throughout the season. The economic threshold for white grubs on corn in Mexico has been estimated at 3 larvae/m<sup>2</sup> (Villalobos 1992), much higher than the densities observed in this study. Tillage has been cited as a factor in reducing white grub populations on small-scale farms in the region (Carballo and Saunders 1990, Cuevas García 1993, Trabanino et al. 1990), and the thorough land preparation in this study may have contributed to the low populations.

#### Beneficial Insect Populations on Corn

Natural enemies occasionally collected or reared from pests on corn and secondary crops are given in Table 3-4. Carabid beetles, which can be important predators in cornfields (Best et al. 1981), were prevalent in pitfall traps of all cropping systems. Carabids present included *Agonum* spp., *Bembidion* sp. and undetermined Platynini and Harpalini.

Table 3-4. Insect natural enemies collected in corn-based cropping systems.

| Order      | Family          | Sub-family, genus or species              | Crop                       |
|------------|-----------------|-------------------------------------------|----------------------------|
| Dermaptera |                 |                                           |                            |
|            | Forficulidae    | <i>Doru</i> sp.                           | Corn                       |
| Hemiptera  |                 |                                           |                            |
|            | Enicocephalidae | <i>Systelloderus</i> sp.                  | Corn                       |
|            | Phymatidae      | <i>Phymata fasciata</i> (Say)             | Corn                       |
|            | Pentatomidae    | <i>Perillus</i> sp.                       | Corn                       |
|            |                 | <i>Cosmopepla decorata</i> (Hahn)         | Amaranth                   |
| Neuroptera |                 |                                           |                            |
|            | Hemerobiidae    | <i>Hemerobius</i> sp.                     | Corn, beans, faba beans    |
| Coleoptera |                 |                                           |                            |
|            | Carabidae       | Harpilini undet.                          | Pitfall trap               |
|            |                 | Platynini undet.                          | Pitfall trap               |
|            |                 | <i>Agonum</i> sp. 1                       | Corn                       |
|            |                 | <i>Agonum</i> sp. 2                       | Corn                       |
|            |                 | <i>Bembidion</i> sp.                      | Wireworm bait              |
|            | Lampyridae      | <i>Photinus</i> sp. 1                     | Corn                       |
|            |                 | <i>Photinus</i> sp. 1                     | Corn                       |
|            | Cantharidae     | <i>Polemus</i> sp. 1                      | Corn, faba bean            |
|            |                 | <i>Polemus</i> sp. 2                      | Corn                       |
|            | Cleridae        | <i>Enoclerus salvini</i> (Garham)         | Corn                       |
|            |                 | <i>Isohydnocera</i> sp.                   | Amaranth                   |
|            | Melyridae       | <i>Collops</i> sp.                        | Corn                       |
|            | Silvidae        | <i>Telephanus</i> CNC 32                  | Bait, corn, beans          |
|            | Coccinellidae   | <i>Anatis lecontei</i> Casey              | Beans                      |
|            |                 | <i>Hippodamia convergens</i> Guerin       | Corn, broccoli             |
|            |                 | <i>Cycloneda sanguinea sanguinea</i> (L.) | Corn, beans, faba beans    |
|            |                 | <i>Scymnus</i> sp. 1                      | Corn                       |
|            |                 | <i>Scymnus</i> sp. 2                      | Corn                       |
| Diptera    |                 |                                           |                            |
|            | Dolichopodidae  | <i>Condyllostylus patibulatus</i> (Say)   | Corn                       |
|            | Syrphidae       | <i>Baccha</i> sp.                         | Corn                       |
|            |                 | <i>Toxomerus</i> sp. 1                    | Corn                       |
|            |                 | <i>Toxomerus</i> sp. 2                    | Corn                       |
|            | Tachinidae      | <i>Peleteria</i> sp.                      | Corn ( <i>Spodoptera</i> ) |

Table 3-4—Continued.

| Order       | Family        | Sub-family, genus or species                  | Crop                                  |
|-------------|---------------|-----------------------------------------------|---------------------------------------|
| Hymenoptera |               |                                               |                                       |
|             | Braconidae    | <i>Cotesia</i> sp. 1                          | Corn ( <i>Spodoptera frugiperda</i> ) |
|             |               | <i>Cotesia</i> sp. 2                          | Corn ( <i>Heliothis zea</i> )         |
|             | Aphidiidae    | <i>Aphidius</i> sp. 1                         | Faba beans                            |
|             |               | <i>Aphidius</i> sp. 2                         | Broccoli                              |
|             |               | <i>Aphidius</i> sp. 4                         | Faba beans                            |
|             | Ichneumonidae | <i>Netelia</i> sp.                            | Corn                                  |
|             |               | Gelini undet.                                 | Corn                                  |
|             |               | <i>Campeletis</i> sp.                         | Corn ( <i>S. frugiperda</i> )         |
|             |               | <i>Diadegma</i> sp.                           | Corn ( <i>S. frugiperda</i> )         |
|             |               | <i>Chiloplatys</i> sp.                        | Corn                                  |
|             |               | <i>Mesochorus</i> sp.                         | Corn, bean                            |
|             | Eulophidae    | <i>Pnigmalio</i> sp. 1                        | Corn (leafminer)                      |
|             |               | <i>Pnigmalio</i> sp. 2                        | Corn (leafminer)                      |
|             |               | <i>Euplectrus</i> sp.                         | Corn ( <i>S. frugiperda</i> )         |
|             | Pteromalidae  | <i>Pteromalus</i> sp.                         | Corn ( <i>Sitotrega cerealella</i> )  |
|             | Tiphiidae     | <i>Tiphia</i> sp. 1                           | Corn                                  |
|             |               | <i>Tiphia</i> sp. 2                           | Corn                                  |
|             | Pompilidae    | <i>Pepsis</i> sp.                             | Corn (spiders)                        |
|             |               | <i>Priocnessus</i> sp.                        | Corn (spiders)                        |
|             | Scoliidae     | <i>Campsomeris quadrimaculata</i> (Fabricius) | Corn                                  |
|             | Vespididae    | <i>Epipona</i> sp.                            | Corn                                  |
|             |               | <i>Polistes</i> sp.                           | Corn                                  |
|             |               | <i>Polybia</i> sp.                            | Faba beans                            |

The most common beneficials found in all cropping systems were generalist predators and natural enemies of aphids and *S. frugiperda*. Andrews (1980, 1988) cites 11 parasites of *S. frugiperda* collected in Central America (including *Apanteles* sp., *Chelonus* spp., *Euplectrus* sp. and *Trichogramma* sp.) and 63 species reported from Latin America. In the present study, in addition to ichneumonid parasitoids (*Campoletis* sp. and *Diadegma* sp.), a number of parasites and predators attacked *S. frugiperda* larvae, including the eulophid parasitoid *Euplectrus* sp., the tachinid *Peleteria* sp., the earwig *Doru* sp. and the syrphids *Baccha* sp. and *Toxomerus* sp. The syrphid larvae were observed consuming early instars of *S. frugiperda*. *Doru* sp. earwigs have been reported to enter corn whorls and feed on small and medium fall armyworm larvae, and *Polistes* sp. wasps also attack *Spodoptera* spp. larvae (Andrews 1980). Wasps of *Polistes* sp. were observed on corn only rarely. The clerid predator *Enoclerus salvini* (Garham) was always observed within the corn whorl, although it was not observed consuming fall armyworm larvae.

Parasitism of *S. frugiperda* has been seen to be higher in corn-bean and corn-weed polycultures than in corn monoculture (Cortez and Trujillo 1994, Altieri 1980). Although density of *S. frugiperda* was greater in corn monoculture in this study, as discussed earlier, densities of fall armyworm parasitoids (*Campoletis* sp. and *Diadegma* sp.) did not differ by cropping system. Percentage parasitism was not measured here, but in Mexico and the southern United States, parasitism rates of the fall armyworm of up to 32.5% have been reported (Pair et al. 1986).

Of the natural enemies whose densities were sampled, only spiders had a higher density in the low-risk intercrop than the other two treatments on one sampling date (Table 3-5). This was not a seasonal trend.

Table 3-5. Densities of spiders on corn in monoculture, intercropped with black beans, faba beans and broccoli (high-risk), and intercropped with black beans, amaranth and cilantro (low-risk), at 6 weeks after planting (mean no. per 0.6 m-row corn  $\pm$  SEM).

|                     |      |       |      |   |
|---------------------|------|-------|------|---|
| Low-risk intercrop  | 0.29 | $\pm$ | 0.11 | a |
| High-risk intercrop | 0.06 | $\pm$ | 0.04 | b |
| Monoculture         | 0.00 | $\pm$ | 0.00 | b |

Treatment means followed by the same letter are not significantly different at  $\alpha=0.05$  ( $n=6$ , ANOVA and Student-Newman-Keuls test performed on data transformed by  $\log_{10}(x+1)$ ).

The densities of all other natural enemies (syrphids, *Hemerobius* sp. lacewings, the coccinellid *Cycloneda sanguinea* (L.), aphid mummies, *Doru* sp., and the clerid beetle *E. salvini*) did not differ by cropping system, either for individual sampling dates or over the season (Table 3-6). Therefore, densities of natural enemies were not influenced by the cropping systems tested. The alternative intercrops tested did not reduce the level of natural control of corn pests and therefore would not contribute to greater pest damage as a result, as long as natural enemies are maintained in the systems.

### Corn Diseases

The most prevalent disease observed on corn over the sampling period was rust (*Puccinia* sp.). The percent of corn plants with signs of rust was greater



Table 3-6. Seasonal mean densities of key beneficials (no. per 0.6 m-row corn  $\pm$  SEM) on corn in monoculture, intercropped with black beans, faba beans and broccoli (high-risk intercrop), and intercropped with black beans, cilantro and amaranth (low-risk intercrop), during the rainy season of 1996.

|                     | Syrphids ( <i>Baccha</i> sp. and <i>Toxomerus</i> sp.) |  | <i>Hemerobius</i> sp. |  | Spiders                         |  | <i>Cycloneda sanguinea</i> adults                                                 |  |
|---------------------|--------------------------------------------------------|--|-----------------------|--|---------------------------------|--|-----------------------------------------------------------------------------------|--|
|                     | Mean $\pm$ SEM                                         |  | Mean $\pm$ SEM        |  | Mean $\pm$ SEM                  |  | Mean $\pm$ SEM                                                                    |  |
| Corn monoculture    | 0.112 $\pm$ 0.023                                      |  | 0.024 $\pm$ 0.007     |  | 0.037 $\pm$ 0.009               |  | 0.009 $\pm$ 0.003                                                                 |  |
| High-risk intercrop | 0.149 $\pm$ 0.026                                      |  | 0.053 $\pm$ 0.019     |  | 0.032 $\pm$ 0.007               |  | 0.024 $\pm$ 0.007                                                                 |  |
| Low-risk intercrop  | 0.133 $\pm$ 0.025                                      |  | 0.013 $\pm$ 0.005     |  | 0.052 $\pm$ 0.011               |  | 0.014 $\pm$ 0.005                                                                 |  |
|                     | Aphid mummies                                          |  | <i>Doru</i> sp.       |  | <i>Enoclerus salvini</i> adults |  | Parasitoids of <i>Spodoptera</i> ( <i>Camptoplex</i> sp. and <i>Diadegma</i> sp.) |  |
|                     | Mean $\pm$ SEM                                         |  | Mean $\pm$ SEM        |  | Mean $\pm$ SEM                  |  | Mean $\pm$ SEM                                                                    |  |
| Corn monoculture    | 0.032 $\pm$ 0.011                                      |  | 0.010 $\pm$ 0.005     |  | 0.006 $\pm$ 0.003               |  | 0.006 $\pm$ 0.003                                                                 |  |
| High-risk intercrop | 0.019 $\pm$ 0.007                                      |  | 0.004 $\pm$ 0.002     |  | 0.008 $\pm$ 0.003               |  | 0.006 $\pm$ 0.003                                                                 |  |
| Low-risk intercrop  | 0.032 $\pm$ 0.009                                      |  | 0.004 $\pm$ 0.002     |  | 0.003 $\pm$ 0.002               |  | 0.005 $\pm$ 0.003                                                                 |  |

No significant differences were found among treatment means for any arthropod ( $\alpha=0.05$ ,  $n=120$ , ANOVA and Student-Newman-Keuls test performed on data transformed by  $\log_{10}(x+1)$ ).

on corn in monoculture during most of the season (Figure 3-3). Nevertheless, the seasonal mean percentage of infested corn plants showed no difference among treatments. On one sampling date (8 weeks after planting), the percentage of corn plants with rust was significantly lower in the high-risk treatment (corn with black beans, faba beans and broccoli) than in the other 2 treatments (Table 3-7). Although close to 40% of plants were infected by the later sampling dates, rust was observed to affect no more than 1% of foliage in any sample.

Table 3-7. Percentage of corn plants infested with rust when grown in monoculture, intercropped with black beans, faba beans and broccoli (high-risk), and intercropped with black beans, amaranth and cilantro (low-risk), at 8 weeks after planting (mean  $\pm$  SEM).

|                     |       |       |      |   |
|---------------------|-------|-------|------|---|
| Monoculture         | 18.42 | $\pm$ | 3.45 | a |
| Low-risk intercrop  | 13.50 | $\pm$ | 2.53 | a |
| High-risk intercrop | 8.33  | $\pm$ | 2.66 | b |

Treatment means followed by the same letter are not significantly different at  $\alpha=0.05$  ( $n=6$ , ANOVA and Student-Newman-Keuls test performed on data transformed by square root).

The other two leaf spots infecting corn (caused by *Helminthosporium* sp. and *Phyllachora maydis* Maubl.) were also unaffected by cropping system treatment. *H. turcicum* Passerini, *H. maydis* (Nisikado et Myiye) and *P. maydis* Maubl. are common on corn in Central America but do not affect the crop economically unless conditions are favorable for disease development and the corn is highly susceptible (CATIE 1990a). In the present study, *Helminthosporium* sp. was present on nearly all corn plants by the end of the season, but like rust, affected less than 1% of leaf area. Also, when the disease

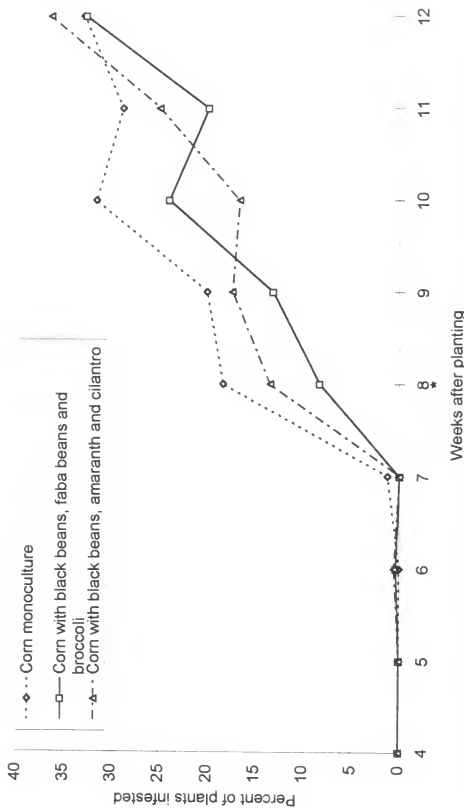


Figure 3-3. Mean percentage of plants infested with rust (*Puccinia* sp.) on corn in monoculture, corn intercropped with black beans, faba beans and broccoli, and corn intercropped with black beans, amaranth, and cilantro, during the rainy season of 1996. Asterisk indicates sampling date with significant treatment difference ( $\alpha=0.06$ ,  $n=6$ , ANOVA and Student-Newman-Keuls test performed on data transformed by square root).

develops 6 weeks after silking there is little to no effect on yield (Shurtleff 1980), and its incidence did not increase until late in the season. Tar spot, caused by *P. maydis*, occurs mostly in cool, humid areas of the tropics in conjunction with Northern corn leaf blight (*H. turcicum*) (Shurtleff 1980). Disease symptoms were not apparent until the final weeks of the season.

Additionally, *Fusarium* sp. was infrequently observed causing stem rot and ear rot. *Penicillium* sp. ear rot was also present at low levels, as was corn smut (*Ustilago maydis* (DC) Cda), which affected ears, foliage and tassels. Severity of all of the diseases on corn was low, and no differences among treatments in seasonal mean densities were seen for any of the diseases sampled (Table 3-8).

### Damage Estimates

Over the season, however, insects damaged a greater percentage of corn plants when in monoculture than in either intercrop (Figure 3-4 and Tables 3-8 and 3-9). This is probably the result of the higher density of *S. frugiperda* larvae on corn in monoculture. Percentage of plants damaged by *S. frugiperda*, while not significantly different on individual sampling dates or the seasonal mean, was nevertheless higher than the other treatments and for much of the season contributed to a substantial portion of total insect damage.

Densities and resulting damage from *S. frugiperda* were low until mid-season, however. Effects of plant maturity on susceptibility of corn to armyworm attack appear to be variable. Harrison (1984) reported that corn plants (variety

Table 3-8. Seasonal mean percentage (mean  $\pm$  SEM) of corn plants with disease and damage in monoculture, intercropped with black beans, faba beans and broccoli (high-risk intercrop), and intercropped with black beans, cilantro and amaranth (low-risk intercrop), during the rainy season of 1996.

|                              | <i>Rust (Puccinia sp.)</i> |  | <i>Helminthosporium</i><br>sp |  | <i>Phyllachora maydis</i> |  |
|------------------------------|----------------------------|--|-------------------------------|--|---------------------------|--|
|                              | Mean $\pm$ SEM             |  | Mean $\pm$ SEM                |  | Mean $\pm$ SEM            |  |
| Corn monoculture             | 11.765 $\pm$ 1.125 a       |  | 3.108 $\pm$ 0.761 a           |  | 2.823 $\pm$ 0.575 a       |  |
| High-risk intercrop          | 8.742 $\pm$ 0.958 a        |  | 3.247 $\pm$ 0.751 a           |  | 2.842 $\pm$ 0.638 a       |  |
| Low-risk intercrop           | 9.598 $\pm$ 0.962 a        |  | 3.281 $\pm$ 0.822 a           |  | 3.281 $\pm$ 0.771 a       |  |
| Damage from                  |                            |  |                               |  |                           |  |
| Total insect damage          |                            |  |                               |  |                           |  |
| <i>Spodoptera frugiperda</i> |                            |  |                               |  |                           |  |
|                              | Mean $\pm$ SEM             |  | Mean $\pm$ SEM                |  | Mean $\pm$ SEM            |  |
| Corn monoculture             | 11.560 $\pm$ 0.986 a       |  | 4.658 $\pm$ 0.661 a           |  | 7.045 $\pm$ 0.988 a       |  |
| High-risk intercrop          | 7.662 $\pm$ 0.775 b        |  | 3.516 $\pm$ 0.531 a           |  | 7.735 $\pm$ 1.292 a       |  |
| Low-risk intercrop           | 9.075 $\pm$ 0.878 b        |  | 3.510 $\pm$ 0.570 a           |  | 6.386 $\pm$ 0.898 a       |  |

Treatment means followed by the same letter are not significantly different ( $\alpha=0.05$ ,  $n=120$ , ANOVA and Student-Newman-Keuls test performed on data transformed by square root).

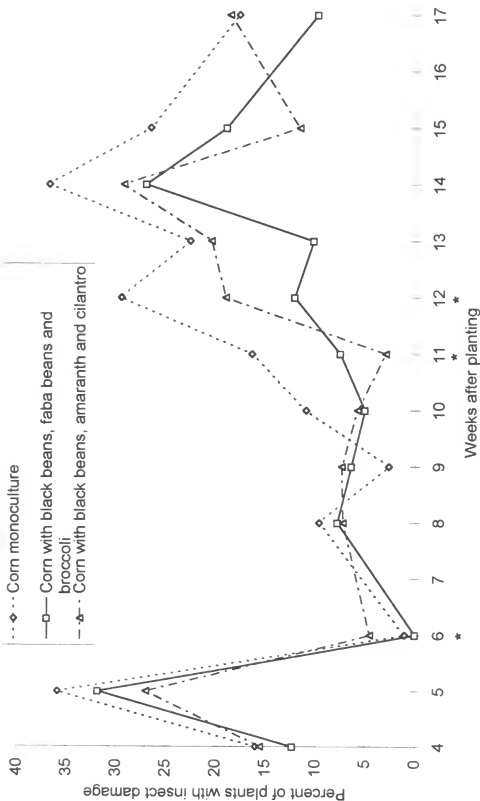


Figure 3-4. Mean percentage of plants with insect damage on corn in monoculture, corn intercropped with black beans, faba beans and broccoli, and corn intercropped with black beans, amaranth, and cilantro, during the rainy season of 1996. Asterisks by sampling dates indicate significant treatment differences ( $\alpha=0.05$ ,  $n=6$ , ANOVA and Student-Newman-Keuls test performed on data transformed by square root).

not specified) infested early in development were less tolerant to fall armyworm attack, while a locally developed variety in Nicaragua was found to be more tolerant to armyworm infestation during early growth (Hruska and Gould 1997). Economic injury levels developed for corn in Latin America have been estimated as 23-63% of plants infested over a range of potential yields in Nicaragua (Hruska and Gould 1997) and 11-42% over the first 6 weeks in Ecuador (Evans and Stansly 1990).

Table 3-9. Percentage of corn plants with insect damage (mean  $\pm$  SEM) when grown in monoculture, intercropped with black beans, faba beans and broccoli (high-risk), and intercropped with black beans, amaranth and cilantro (low-risk), during the dry season of 1996.

|                     | Week 6            | Week 11            | Week 12             |
|---------------------|-------------------|--------------------|---------------------|
| Monoculture         | 1.04 $\pm$ 0.73 b | 16.34 $\pm$ 3.63 a | 29.40 $\pm$ 4.99 a  |
| High-risk intercrop | 0.00 $\pm$ 0.00 b | 7.50 $\pm$ 2.60 b  | 12.08 $\pm$ 2.96 b  |
| Low-risk intercrop  | 4.51 $\pm$ 1.97 a | 2.96 $\pm$ 1.80 b  | 18.93 $\pm$ 3.50 ab |

Treatment means followed by the same letter are not significantly different at  $\alpha=0.05$  (n=6, ANOVA and Student-Newman-Keuls test performed on data transformed by square root).

Until more information is collected for small-scale Guatemalan farmers, however, the most appropriate action threshold would be one developed at the Escuela Agrícola Panamericana for small-scale Honduran farmers. That threshold is a 40% infestation rate based on a sample of 5 sites with 20 plants at each (Andrews 1988). In the present study, percentage of plants infested was below the Honduran threshold for all sampling dates, and therefore chemical

control of *S. frugiperda* on corn would not be recommended for any of the cropping systems tested.

Lodging of corn plants was high, but it is a common occurrence in the area with the strong winds that usually begin toward the end of the rainy season. However, there was no effect of cropping system on the mean percentage of corn plants lodged (Figure 3-5, Table 3-8). Other damage to corn ears resulted from attack by insects, rats, squirrels, birds, smut, and rotting due to excess moisture. Rotting was the most prevalent form of damage and the only one in which a difference was observed among treatments, at 26 weeks after planting. The high-risk treatment (corn with black beans, faba beans and broccoli) had a higher percentage of ears damaged by rotting than the monoculture (Table 3-10). However, this was not repeated on other sampling dates. Insect damage was second to rotting in prevalence over all dates.

Table 3-10. Percentage of corn ears damaged by rotting when grown in monoculture, intercropped with black beans, faba beans and broccoli (high-risk), and intercropped with black beans, amaranth and cilantro (low-risk), (mean  $\pm$  SEM), November 13, 1996.

|                     |       |       |      |    |
|---------------------|-------|-------|------|----|
| High-risk intercrop | 48.65 | $\pm$ | 7.00 | a  |
| Low-risk intercrop  | 36.78 | $\pm$ | 7.26 | ab |
| Monoculture         | 23.00 | $\pm$ | 5.26 | b  |

Treatment means followed by the same letter are not significantly different at  $\alpha=0.05$  ( $n=6$ , ANOVA and Student-Newman-Keuls test performed on data transformed by square root).

At the time of harvest, there were no differences among cropping system treatments in percent of ears or percentage of kernels damaged by any source



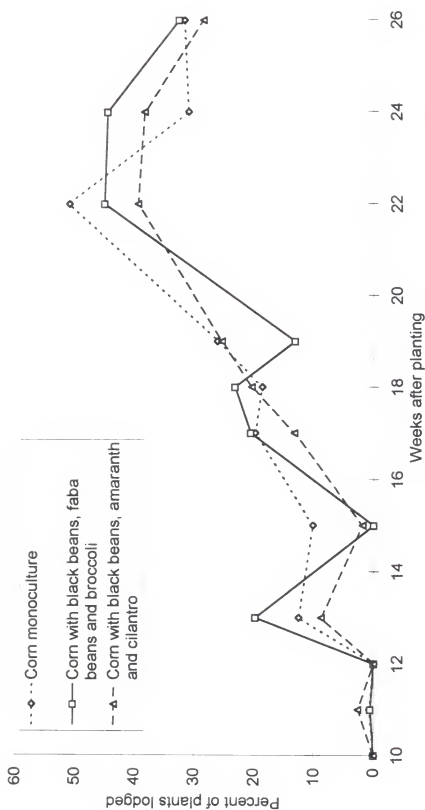


Figure 3-5. Mean percentage of lodged corn plants in monoculture, corn intercropped with black beans, faba beans and broccoli, and corn intercropped with black beans, amaranth and cilantro, during the rainy season of 1996. No significant differences were detected for any sampling date ( $\alpha=0.05$ ,  $n=6$ , ANOVA and Student-Newman-Keuls test performed on data transformed by square root).

(insects, rats, squirrels, birds, *Fusarium* ear rot, smut, rotting, unfilled kernels, cracked kernels and damage from all sources). Additionally, cropping system had no effect on development of grain, in terms of size and weight of ears, number of ears per plant, or number of kernels per ear (Tables 3-11 and 3-12).

### Insects and Diseases on Secondary Crops

Few insect and disease problems were evident in the amaranth and cilantro planted in the low-risk intercrop. Amaranth showed a low level of defoliation from lepidopteran larvae, and the most common insects observed on seedheads were leafhoppers, principally *Graphocephala* spp. and *Macrostelus* sp. No signs or symptoms of disease were observed on this crop. Cilantro had even fewer potential pests, since no insect pests or diseases were ever observed. The only damage to cilantro was mechanical, as a result of lodged corn plants.

The high-risk intercrop, however, did experience insect and disease pest problems. Root rot caused by *Rhizoctonia* sp. was the major factor in reducing yield in faba beans, since plants were severely attacked, turning completely black in some cases. By the time of the first harvest, 98.3% of faba bean plants were affected by *Rhizoctonia* rot and 35% were dead as a result. Ninety-seven percent of plants at that time showed signs of *Ascochyta* sp.-induced leaf spot, which did not affect the plants as severely, and 83.3% showed signs of rust. The major direct damage to the pods was due to birds, but only 9% of pods at harvest had bird damage, the effects of fallen corn being more consequential

Table 3-11. Damage to corn ears sampled at harvest (November 26, 1996), by source of damage (mean % of ears  $\pm$  SEM), for corn in monoculture, corn intercropped with black beans, faba beans and broccoli (high-risk intercrop), and corn intercropped with black beans, cilantro and amaranth (low-risk intercrop).

|                     | Percent of ears<br>damaged by insects         |            | Percent of ears<br>damaged by rats |            | Percent of ears<br>damaged by squirrels |            | Percent of ears<br>damaged by birds         |            |
|---------------------|-----------------------------------------------|------------|------------------------------------|------------|-----------------------------------------|------------|---------------------------------------------|------------|
|                     | Mean                                          | $\pm$ SE   | Mean                               | $\pm$ SE   | Mean                                    | $\pm$ SE   | Mean                                        | $\pm$ SE   |
| Corn monoculture    | 17.80                                         | $\pm$ 3.54 | 6.98                               | $\pm$ 3.94 | 3.62                                    | $\pm$ 1.85 | 10.13                                       | $\pm$ 3.54 |
| High-risk intercrop | 24.40                                         | $\pm$ 4.35 | 3.50                               | $\pm$ 2.14 | 9.60                                    | $\pm$ 2.96 | 8.73                                        | $\pm$ 2.23 |
| Low-risk intercrop  | 23.78                                         | $\pm$ 4.57 | 1.83                               | $\pm$ 0.90 | 5.40                                    | $\pm$ 2.40 | 13.34                                       | $\pm$ 3.87 |
|                     | Percent of ears<br>damaged by <i>Fusarium</i> |            | Percent of ears<br>damaged by smut |            | Percent of ears<br>damaged by rotting   |            | Percent of ears<br>with unfilled<br>kernels |            |
|                     | Mean                                          | $\pm$ SE   | Mean                               | $\pm$ SE   | Mean                                    | $\pm$ SE   | Mean                                        | $\pm$ SE   |
| Corn monoculture    | 10.19                                         | $\pm$ 3.11 | 0.63                               | $\pm$ 0.62 | 25.47                                   | $\pm$ 4.60 | 73.77                                       | $\pm$ 6.16 |
| High-risk intercrop | 9.87                                          | $\pm$ 2.59 | 1.40                               | $\pm$ 1.07 | 22.77                                   | $\pm$ 4.58 | 71.60                                       | $\pm$ 4.68 |
| Low-risk intercrop  | 9.73                                          | $\pm$ 3.36 | 6.11                               | $\pm$ 3.26 | 20.87                                   | $\pm$ 3.91 | 70.70                                       | $\pm$ 5.07 |

No significant treatment differences were detected for any measurements ( $\alpha=0.05$ ,  $n=6$ , ANOVA and Student-Newman-Keuls test performed on data transformed by square root).

Table 3-12. Corn ear development and damage to kernels sampled at harvest (November 26, 1996), by source of damage (mean  $\pm$  SEM), for corn in monoculture, corn intercropped with black beans, faba beans and broccoli (high-risk intercrop), and corn intercropped with black beans, cilantro and amaranth (low-risk intercrop).

|                     | Weight (g) per ear (15% moisture)      |  | Length (cm) per ear                      |  | No. ears/plant                          |  | No. kernels/ear                     |  |
|---------------------|----------------------------------------|--|------------------------------------------|--|-----------------------------------------|--|-------------------------------------|--|
|                     | Mean $\pm$ SE                          |  | Mean $\pm$ SE                            |  | Mean $\pm$ SE                           |  | Mean $\pm$ SE                       |  |
| Corn monoculture    | 54.475 $\pm$ 3.370                     |  | 14.221 $\pm$ 0.640                       |  | 0.910 $\pm$ 0.058                       |  | 290.581 $\pm$ 14.954                |  |
| High-risk intercrop | 60.944 $\pm$ 3.930                     |  | 15.245 $\pm$ 0.589                       |  | 0.902 $\pm$ 0.067                       |  | 302.146 $\pm$ 13.818                |  |
| Low-risk intercrop  | 56.991 $\pm$ 3.771                     |  | 14.484 $\pm$ 0.770                       |  | 0.827 $\pm$ 0.076                       |  | 283.561 $\pm$ 16.409                |  |
|                     | Percent of kernels damaged by insects  |  | Percent of kernels damaged by rats       |  | Percent of kernels damaged by squirrels |  | Percent of kernels damaged by birds |  |
|                     | Mean $\pm$ SE                          |  | Mean $\pm$ SE                            |  | Mean $\pm$ SE                           |  | Mean $\pm$ SE                       |  |
| Corn monoculture    | 1.197 $\pm$ 0.341                      |  | 0.729 $\pm$ 0.551                        |  | 0.726 $\pm$ 0.519                       |  | 0.636 $\pm$ 0.278                   |  |
| High-risk intercrop | 1.070 $\pm$ 0.302                      |  | 2.745 $\pm$ 1.728                        |  | 1.149 $\pm$ 0.662                       |  | 0.726 $\pm$ 0.205                   |  |
| Low-risk intercrop  | 0.671 $\pm$ 0.203                      |  | 0.284 $\pm$ 0.196                        |  | 0.565 $\pm$ 0.449                       |  | 1.171 $\pm$ 0.397                   |  |
|                     | Percent of kernels damaged by Fusarium |  | Percent of kernels damaged by smut       |  | Percent of kernels damaged by rotting   |  | Percent of kernels unfilled         |  |
|                     | Mean $\pm$ SE                          |  | Mean $\pm$ SE                            |  | Mean $\pm$ SE                           |  | Mean $\pm$ SE                       |  |
| Corn monoculture    | 0.668 $\pm$ 0.355                      |  | 0.110 $\pm$ 0.105                        |  | 2.112 $\pm$ 0.595                       |  | 15.240 $\pm$ 1.548                  |  |
| High-risk intercrop | 1.803 $\pm$ 0.758                      |  | 0.017 $\pm$ 0.016                        |  | 2.798 $\pm$ 1.002                       |  | 19.372 $\pm$ 2.934                  |  |
| Low-risk intercrop  | 1.099 $\pm$ 0.498                      |  | 0.000 $\pm$ 0.000                        |  | 2.698 $\pm$ 0.766                       |  | 21.527 $\pm$ 3.436                  |  |
|                     | Percent of kernels cracked             |  | Percent of kernels damaged (all sources) |  |                                         |  |                                     |  |
|                     | Mean $\pm$ SE                          |  | Mean $\pm$ SE                            |  |                                         |  |                                     |  |
| Corn monoculture    | 0.134 $\pm$ 0.060                      |  | 20.485 $\pm$ 1.778                       |  |                                         |  |                                     |  |
| High-risk intercrop | 0.121 $\pm$ 0.070                      |  | 29.282 $\pm$ 3.542                       |  |                                         |  |                                     |  |
| Low-risk intercrop  | 0.209 $\pm$ 0.106                      |  | 25.275 $\pm$ 3.345                       |  |                                         |  |                                     |  |

No significant treatment differences were detected for any measurements ( $\alpha=0.05$ ,  $n=6$ , ANOVA and Student-Newman-Keuls test performed on data transformed by  $\log_{10}(x+1)$  for no. ears/plant and no. kernels/ear, and by square root for percents).

(14.5% of plants). The key insect on faba beans was the bean aphid, *Aphis fabae* Scopoli, which at times reached very high densities on individual plants.

Broccoli was damaged to some degree by foliar diseases (alternaria leaf spot, caused by *Alternaria brassicae* (Berk.) Sacc. and downy mildew of crucifers, caused by *Peronospora parasitica* Pers. Ex. Fr.). Downy mildew, while affecting more plants, produced less damage than *Alternaria*, which was recorded in only 8.2% of plants. The principal insect pest on broccoli was the cabbage white butterfly, *Leptophobia aripa* (Boisd.), the larvae of which were present on between 5.5 and 33.3% of plants during the season. This pest can be particularly damaging in small plots in Central America, and the threshold is 10% of plants with eggs or larvae (King and Saunders 1984).

In both intercrops, bean plants were heavily defoliated by the chrysomelid beetle *D. wagneri*, which was consistently present in higher numbers in the high-risk than in the low-risk intercrop (Figure 3-6). The reason for this difference is not clear and requires further study. In addition, bean rust (*Uromyces phaseoli* (Pers.) Wint.) and an unidentified leaf spot contributed to highly reduced yields of bean in both treatments.

A number of beneficial insects were present on secondary crops that were not present in corn monoculture (Table 3-2), particularly aphid parasitoids (*Aphidius* sp.). Common predators like *Hemerobius* sp. and *C. sanguinea* were collected from several secondary crops as well as corn. The intercrops have potential for providing favorable conditions for natural control where chemical pesticides are used sparingly.

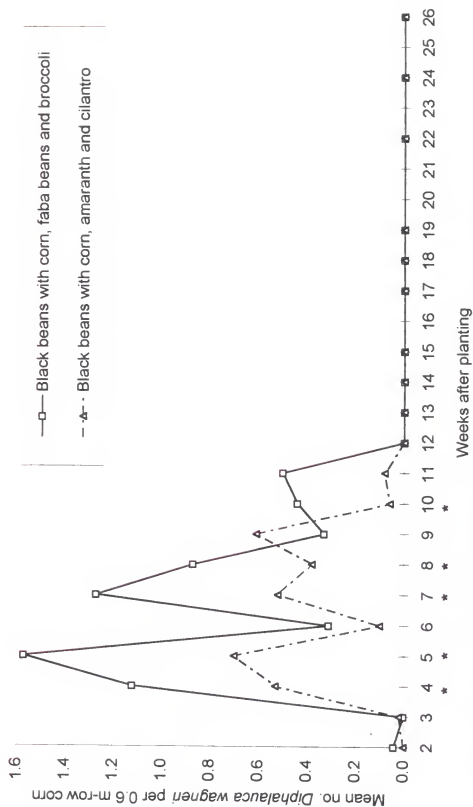


Figure 3-6. Mean densities of the leaf beetle *Diphalauga wagneri* on black beans intercropped with corn, faba beans and broccoli, and black beans intercropped with corn, amaranth and cilantro, during the rainy season of 1996. Asterisks by sampling dates indicate significant treatment differences ( $\alpha=0.05$ ,  $n=6$ ,  $t$ -test performed on data transformed by  $\log(x+1)$ ).

### Conclusions

Before recommending alternative cropping systems hypothesized to better satisfy the economic, nutritional and cultural needs of small-scale tropical farmers, it is essential to ensure that their utilization will not contribute to pest problems in the staple crop. Such problems could result in yield losses that would threaten the already precarious food security of the family. Additionally, they could contribute to greater usage of chemical pesticides, which small-scale farmers in Central America often lack the information and capital to use appropriately. Furthermore, the use of many of the most common synthetic insecticides in the area is not compatible with the strategy of conserving and increasing beneficial populations (Whitcomb 1994). Avoiding these scenarios requires evaluation of any changes in pest density or damage to the staple crop that may come about as a result of adding other crops to the system.

In the present study, there is no evidence that the addition of the selected crops tested would lead to greater pest problems on the staple crop corn. While there were differences among treatments in certain insect pest population densities for some sampling dates, these differences were not generally consistent over the season. One exception was the fall armyworm, which had a higher seasonal mean density in the monoculture than in the high-risk treatment. Probably as a result, the percentage of plants with total insect damage was greater in the monoculture than in the other cropping systems. Since *S. frugiperda* is one of the most important pests of corn in Central America, there

may be an advantage in terms of pest management to the intercropping systems tested.

These alternative intercrops did not affect disease development, damage to ears, or densities of the most abundant natural enemies. Furthermore, chemical control would not be recommended for pests on corn in any of the cropping systems tested. Black bean, however, requires disease and insect control when it is a component of either alternative system. This could be avoided by replacing it with a more resistant traditional bean like piloy (*Phaseolus coccineus* L.) (DeBouck 1994).

Although the additional crops in the low-risk intercrop would not require pest control, additional crops in the high-risk treatment did contribute to the need for pest management. Therefore, of the 2 alternatives tested, the high-risk cropping system is less appropriate for small-scale farmers, while the low-risk intercrop would be favorable in terms of pest management and would be most appropriate if it proves to have additional advantages not related to pest management. Further study of these and other combinations is required to maximize economic and nutritional benefits of the corn cropping system while minimizing the need for the farmer to make pest management decisions.



## CHAPTER 4

### INSECT PEST AND BENEFICIAL POPULATIONS, DISEASE AND DAMAGE IN BEAN MONOCULTURE AND TWO ALTERNATIVE INTERCROPS

#### Introduction

Crops with both market and nutritional value like tomato and husk tomato can potentially contribute to the improvement of the health and economic condition of small-scale farmers in the western Guatemalan highlands. Black beans are second only to corn in terms of production and consumption by rural families in this area (Proyecto ALA 1987), and therefore black bean cropping systems incorporating one or both of these crops are seemingly advantageous.

Cropping systems designed to meet such non-entomological goals of farmers as profit and nutrition may inadvertently cause greater economic or health threats if added crops amplify insect or disease pest problems to the degree that either yields of the staple food crop decline or added pest control measures become necessary. The effects of additional plants on insect pests and their natural enemies are variable and specific to each pest's ecology (Power et al. 1987, Andow 1991b). Beneficial insects, especially generalist predators and parasites, can play a significant role in the regulation of pest populations and are often inadequately assessed (Gross 1987). Therefore, before recommending crop combinations with the potential to increase economic or nutritional return for small-scale tropical farmers, it is essential to evaluate the

pest and beneficial populations present in the area and determine any potential change in pest pressure on the staple crop as a result of changes in cropping patterns.

Beans in Latin America are attacked by a wide range of insects that feed on seeds, foliage, plant fluids, pods and stored grain. The most serious bean pest in parts of Central America is the leafhopper *Empoasca kraemeri* Ross & Moore, which can cause total loss of the crop (Power et al. 1987, Schwartz et al. 1978). Other common insect pests on bean in the region include the bean-pod weevil (*Apion godmani* Wagner), the Mexican bean beetle (*Epilachna varivestis* Mulsant), whiteflies (*Bemisia tabaci* Gennadius) and slugs. Estimates of loss from the bean-pod weevil in southeastern Guatemala range from 9-60% (Cardona 1989). Nevertheless, little information on prevalent bean pests is available for the western highlands.

Intercropping with beans is common throughout the tropics, and in Latin America beans are most frequently grown with corn. Where reported, the effects of intercropping on bean pests and natural enemies have been variable (Latheef and Irwin 1980, Tingey and Lamont 1988, Perfecto et al. 1986). Tomato and bean intercropping were observed rarely during the preliminary survey of small-scale farmers in the study area, but this intercrop combination has been promoted as part of an IPM program for Central America (Rosset et al. 1987, Power et al. 1987). On the other hand, the production of husk tomato has just recently been identified as a research target within the area of specialty crops in

the U.S. (Can et al. 1991-92, Maynard 1993), and its use in intercropping systems has not been evaluated.

Given the importance of maintaining the yield of beans as a staple crop for farm families in the study area, the experiment described here was undertaken to establish possible impacts of other crops on bean pests and subsequent damage to the plant. The principal objective was to evaluate the consequences of adding tomato or husk tomato to the bean cropping system, in terms of insect pests, disease pathogens, beneficial insects and damage to the bean plant, in addition to pest occurrence on associated crops. The information gained will be useful in evaluating the likelihood that the intercrops proposed as alternatives to bean monoculture would cause an increased need for pest management by the target farmers.

### Methods and Materials

The study site, experimental design, and layout of field plots were described in Chapter 3. Arrangement of crops within biculture plots is indicated in Figure 4-1. Plots planted to corn monoculture (treatment 1) were planted to black bean monoculture for this experiment, immediately following the harvest of corn. Treatment 2 (high-risk intercrop) consisted of black bean intercropped with tomato. Local farmers, who know less about production of tomato than other crops, and cite high incidence of disease, especially during the rainy season, consider it a risky crop.

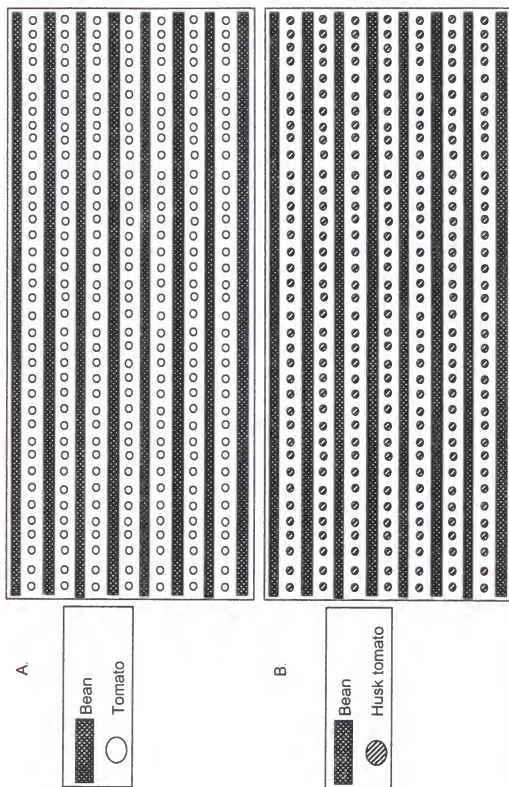


Figure 4-1. Plant arrangements in experimental plots of bean-based cropping systems, with treatments consisting of high-risk intercrop (A), low-risk intercrop (B), and monoculture, with bean planted at equal density.

However, many expressed an interest in growing it, and the increasing local interest in preserved tomato products (sauce and dried tomatoes) suggests that the crop has good local market potential.

Finally, treatment 3 (low-risk intercrop) consisted of black bean intercropped with husk tomato, also called "*tomatillo*," an ancient Mesoamerican crop that is experiencing recent industrialization in Mexico. McBryde (1945) relates that the plant was said to grow well in the Sololá area, and demand for this fruit was high in the region in the early 1940s. It is still widely gathered as a volunteer plant in Guatemala, where it is referred to as "*miltomate*". The small fruit, facilitated in transportation by the husk, is used in green sauces and is experiencing rising demand in the United States due to the growing Mexican population (Montes Hernandez and Aguirre Rivera 1994). In field trials at Bradenton, Florida, the pinworms and sweetpotato whiteflies affecting nearby tomato plants did not affect husk tomato plants (Maynard 1993).

#### Agronomic Management of Field Plots

Plots were cleared of roots and debris from the corn cycle and cultivated with hoes. Locally obtained black bean seed was treated with Captan (N-(trichloromethyl)thio-4-cyclohexane-1,2-dicarboximide) at 2.54 g/kg and planted on December 13, at a spacing of 1 m between rows and 20 cm between plants. Diammonium phosphate (DAP) (18-46-0 NPK) at 100 kg/ha and 2 bean seeds were added to each 10-cm diameter planting hole (50,000 per ha), dug by machete to approximately 5 cm depth. The following week, 6-week old tomato

seedlings were transplanted to all plots of treatment 2, in rows between bean rows at a spacing of 40 cm between plants. Diammonium phosphate at 100 kg/ha was applied to approximately 15-cm diameter holes (23,333 per ha) at transplanting. Five weeks later, tomato plants were staked with 4 rows of string through each row of tomato.

Two weeks after planting beans, 7-week old husk tomato seedlings were transplanted to all treatment 3 plots in the same manner as tomato plants. However, husk tomato plants did not require staking. Both tomato and husk tomato seedlings had been grown in seedbeds into which 15-15-15 NPK fertilizer had been previously incorporated throughout at 50 g/m<sup>2</sup>. Dead tomato and husk tomato seedlings were replaced 1 week after transplanting, and non-germinating bean was reseeded 4 weeks after planting.

At 4 weeks after planting bean, muriate of potash (0-0-60 NPK) and urea (46-0-0 NPK) were broadcast to all plots at 100 kg/ha for monoculture (treatment 1) plots and 150 kg/ha for biculture (treatments 2 and 3) plots. At 7 weeks after planting, a second urea application of the same dosage was applied. Plots were weeded 2 times, at 7 and 10 weeks after planting, utilizing a machete and hoe. During the first weeding, soil was pulled around the base of bean plants to provide them with greater support. One of the areas (2 blocks) required a third weeding at 12 weeks after planting.

All plots were watered 3 times weekly, those in one area (2 blocks) with a hose and those in the other 2 areas with the traditional method, which involved diverting water from a nearby irrigation canal to a furrow above each terrace and

subsequently throwing water on the field with a shallow plastic dish. All plots received approximately 900 liters of water per irrigation session. As with the corn cycle, all work was performed by hand, and local management practices were followed where possible.

#### Insect, Disease and Damage Samples: Visual Observations

Beginning at 3 weeks after planting, beans were sampled weekly for insects and disease. At 3, 5, 7, 9, 11, 13 and 15 weeks after planting, visual observations were made of 5 sample units/plot, measuring 40 cm X 40 cm, centered on the row of beans. Allocation was systematic with a random start. For each, all foliage was carefully examined, and the number of all insects present was recorded, as well as the number of plants with signs or symptoms of each disease.

#### Insect and Disease Samples: Destructive Plant Samples

At 4, 6, 8, 10, 12 and 14 weeks after planting, 5 sample units per plot (40 cm X 40 cm) were again allocated systematically with a random start. Bean plants were cut off at ground level, placed into plastic bags, and stored at 4 - 8°C, to be processed within 10 days. The number of each insect, damage, and presence of disease per plant were recorded. In addition, 5 leaves chosen systematically with a random start from each sample unit were traced, and defoliation from chrysomelids was marked. The tracings were later cut out and passed through a leaf area meter (Li-Cor Model LI-3000A Portable Area Meter),

after which the areas marked as chrysomelid defoliation were cut out. Tracings were passed through the area meter again, and the differences between areas of whole leaves and respective defoliated leaves were used to calculate percentage defoliation.

#### Soil and Pod Samples

At the time of the destructive samples, a block of soil approximately 20 cm X 20 cm X 15 cm deep, centered on the sample unit center, was removed with a machete, placed in a plastic bag, and stored at approximately 6°C until processed within 72 hours. Length, width and weight of root system were measured, roots were examined for insects and disease, and soil was hand searched for insects in a shallow plastic pan.

Additionally, a sample was taken at the time of bean harvest, consisting of 5 sample units per plot, 40 cm X 40 cm, centered on the row of bean plants and allocated systematically with a random start, as for earlier foliage samples. Number of pods per plant, number of beans per pod, insects present, and damage by type were recorded.

#### Samples of Community Composition

As in the corn experiment, presence of insects in each of the cropping systems was monitored throughout the season. In addition to collections during the destructive and visual plant samples, pitfall traps were left in the plots twice. Four 10-ounce plastic drinking cups were left at ground level in each plot (1-2



centered on each terrace). Each was filled with 50 ml of a 50:50 solution of antifreeze and water and emptied after 72 hours. Also, immature insects collected during all sampling were reared to adults, as described for the corn experiment.

Insects collected and reared were identified to genus or species utilizing the collections of the Universidad del Valle de Guatemala and the Florida State Collection of Arthropods. Samples of diseased tissues of all crops were collected during the experiment. Plant pathologists at the Universidad del Valle de Guatemala and a private phytopathology laboratory in Guatemala City (Agri-Lab) analyzed the samples by direct observation and cultures, and in the case of possible bean viruses, by inclusion body examination.

### Statistical Analysis

Analysis of Variance was performed on insect densities, percentage of diseased plants, percentage defoliation, root development and pod damage measurements, after transformation to normalize the data (counts transformed by  $\log_{10}(x + 1)$  and percentages transformed by square root), using the PROC GLM procedure of SAS (SAS Institute 1990). The Student-Newman-Keuls test was used to separate means when significant treatment differences were detected ( $\alpha=0.05$ ). Although treatment differences were measured using transformed data, tables reporting mean values present untransformed data. For insect counts and percent of plants infested with disease, data were analyzed by sample date and also pooled to calculate seasonal means.

## Results and Discussion

### Insect Pest Populations on Bean

The most abundant insect pests sampled on bean plants included the leafminer *Liriomyza huidobrensis* Blanchard, aphids, flea beetles (*Chaetocnema* sp.), leafhoppers (primarily *Empoasca* sp.), whiteflies (*Bemisia tabaci* Gennadius), the bean leafroller (*Urbanus proteus* (L.)), leaf beetles (*Diabrotica balteata* LeConte and *Cerotoma* spp.) and white grubs (*Phyllophaga* sp.). A complete list of insect pests collected on bean during the experiment is given in Table 4-1.

Seasonal mean population densities of the most abundant insects encountered on bean were no different in either intercrop treatment than in the bean monoculture (Table 4-2). The leafminer *L. huidobrensis* was the most abundant insect sampled on bean during the season. However, densities of mines were much lower than those observed in agroecosystems in the vicinity of the experimental site, where leafminer outbreaks were becoming common as a result of overuse of synthetic pesticides, a phenomenon increasingly encountered in Central America (CATIE 1990b). Although there was no difference in seasonal mean population density, at 9 weeks after planting the leafmine density in the monoculture treatment was greater than that in either intercrop (Table 4-3).

Table 4-1. Insect herbivores collected in bean-based cropping systems.

| Order       | Family        | Sub-family, genus or species            | Crop              |
|-------------|---------------|-----------------------------------------|-------------------|
| Hemiptera   |               |                                         |                   |
|             | Miridae       | <i>Creontiades rubrinervis</i> (Stal)   | Bean              |
|             |               | <i>Cyrtocapsus</i> sp.                  | Bean              |
|             | Coreidae      | <i>Spartocera fusca</i> (Thunberg)      | Tomato            |
|             |               | <i>Lygus</i> sp.                        | Bean              |
|             | Pentatomidae  | <i>Acrosternum</i> sp.                  | Bean              |
| Homoptera   |               |                                         |                   |
|             | Membracidae   | <i>Stictocephala lutea</i> (Walker)     | Bean              |
|             |               | <i>Tylopelta</i> sp.                    | Bean              |
|             | Cicadellidae  | <i>Graphocephala</i> sp.                | Bean, husk tomato |
|             |               | <i>Empoasca</i> sp.                     | Bean              |
|             |               | <i>Gyponana</i> sp.                     | Bean              |
|             | Aleyrodidae   | <i>Bemisia tabaci</i> (Gennadius)       | Bean              |
|             | Aphidae       | <i>Aphis craccivora</i> Koch            | Bean              |
|             |               | <i>A. fabae</i> Scopolii                | Bean              |
|             |               | <i>A. gossypii</i> Glover               | Bean              |
|             |               | <i>Brevicoryne brassicae</i> L.         | Tomato, husk tom. |
|             |               | <i>Macrosiphum euphorbiae</i> (Thomas)  | Bean, husk tomato |
|             |               | <i>Picturaphis</i> sp.                  | Bean              |
| Coleoptera  |               |                                         |                   |
|             | Elateridae    | <i>Glyphonyx</i> sp.                    | Bean              |
|             | Coccinellidae | <i>Epilachna mexicana</i> (Guerin)      | Husk tomato       |
|             | Chrysomelidae | <i>Diphalauca wagneri</i>               | Bean              |
|             |               | <i>Diabrotica balteata</i> Lec.         | Bean, tomato      |
|             |               | <i>Cerotoma ruficornis</i> (Oliv.)      | Bean              |
|             |               | <i>C. atrofasciata</i> Jacoby           | Bean              |
|             |               | <i>Chaetocnema</i> sp. 1                | Husk tomato       |
|             |               | <i>Chaetocnema</i> sp. 2                | Bean              |
|             |               | <i>Strabala</i> sp.                     | Husk tomato       |
|             | Apionidae     | <i>Apion</i> sp.                        | Bean              |
| Diptera     |               |                                         |                   |
|             | Agromyzidae   | <i>Liriomyza huidobrensis</i> Blanchard | Bean, husk tomato |
| Lepidoptera |               |                                         |                   |
|             | Hesperiidae   | <i>Urbanus proteus</i> (L.)             | Bean              |
|             | Arctiidae     | <i>Estigmene acrea</i> (Drury)          | Bean              |
|             | Noctuidae     | <i>Helicoverpa zea</i> (Boddie)         | Tomato            |

Table 4-2. Seasonal densities of key insects (mean no. per 0.4 m-row beans  $\pm$  SEM) and mean percent of plants infested with disease on beans in monoculture, intercropped with tomato (high-risk intercrop), and intercropped with husk tomato (low-risk intercrop).

|                     | <i>Liriomyza</i>          |  | aphids                 |  | <i>Chaetocnema</i> sp.       |  | leafhoppers                               |  |
|---------------------|---------------------------|--|------------------------|--|------------------------------|--|-------------------------------------------|--|
|                     | <i>huidobrensis</i> mines |  |                        |  |                              |  |                                           |  |
|                     | Mean $\pm$ SEM            |  | Mean $\pm$ SEM         |  | Mean $\pm$ SEM               |  | Mean $\pm$ SEM                            |  |
| Bean monoculture    | 7.356 $\pm$ 0.396         |  | 0.246 $\pm$ 0.048      |  | 0.033 $\pm$ 0.010            |  | 0.056 $\pm$ 0.013                         |  |
| High-risk intercrop | 6.656 $\pm$ 0.393         |  | 0.218 $\pm$ 0.040      |  | 0.031 $\pm$ 0.010            |  | 0.044 $\pm$ 0.013                         |  |
| Low-risk intercrop  | 6.472 $\pm$ 0.406         |  | 0.233 $\pm$ 0.047      |  | 0.072 $\pm$ 0.015            |  | 0.059 $\pm$ 0.013                         |  |
|                     | <i>Empoasca</i> sp.       |  | <i>Bemisia tabaci</i>  |  | <i>Urbanus proteus</i>       |  | <i>Diabrotica balteata</i>                |  |
|                     | Mean $\pm$ SEM            |  | Mean $\pm$ SEM         |  | Mean $\pm$ SEM               |  | Mean $\pm$ SEM                            |  |
| Bean monoculture    | 0.038 $\pm$ 0.010         |  | 0.046 $\pm$ 0.013      |  | 0.028 $\pm$ 0.009            |  | 0.003 $\pm$ 0.003                         |  |
| High-risk intercrop | 0.026 $\pm$ 0.008         |  | 0.049 $\pm$ 0.015      |  | 0.036 $\pm$ 0.012            |  | 0.010 $\pm$ 0.006                         |  |
| Low-risk intercrop  | 0.036 $\pm$ 0.009         |  | 0.079 $\pm$ 0.019      |  | 0.023 $\pm$ 0.008            |  | 0.000 $\pm$ 0.000                         |  |
|                     | <i>Ceratomya</i> spp.     |  | <i>Phyllophaga</i> sp. |  | <i>Brachiacaantha lepida</i> |  | Bean rust<br>( <i>Uromyces phaseoli</i> ) |  |
|                     | Mean $\pm$ SEM            |  | Mean $\pm$ SEM         |  | Mean $\pm$ SEM               |  | Mean $\pm$ SEM                            |  |
| Bean monoculture    | 0.021 $\pm$ 0.008         |  | 0.039 $\pm$ 0.014      |  | 0.005 $\pm$ 0.004            |  | 15.952 $\pm$ 1.594                        |  |
| High-risk intercrop | 0.021 $\pm$ 0.007         |  | 0.028 $\pm$ 0.012      |  | 0.008 $\pm$ 0.006            |  | 14.889 $\pm$ 1.553                        |  |
| Low-risk intercrop  | 0.021 $\pm$ 0.007         |  | 0.017 $\pm$ 0.010      |  | 0.005 $\pm$ 0.004            |  | 13.484 $\pm$ 1.500                        |  |
|                     | Leaf spot                 |  | Root rot               |  | <i>Rhizoctonia</i> sp.)      |  |                                           |  |
|                     | Mean $\pm$ SEM            |  | Mean $\pm$ SEM         |  | Mean $\pm$ SEM               |  |                                           |  |
| Bean monoculture    | 1.888 $\pm$ 0.451         |  | 0.778 $\pm$ 0.377      |  |                              |  |                                           |  |
| High-risk intercrop | 2.770 $\pm$ 0.634         |  | 0.867 $\pm$ 0.384      |  |                              |  |                                           |  |
| Low-risk intercrop  | 3.526 $\pm$ 0.763         |  | 2.444 $\pm$ 0.823      |  |                              |  |                                           |  |

No significant differences among treatments were detected for any densities or percentage of plants infested ( $\alpha=0.05$ ,  $n=98$ , ANOVA and Student-Newman-Keuls test performed on data transformed by  $\log_{10}(x+1)$  for densities and by square root for percents).

Table 4-3. Densities (mean no. per 0.4 m-row bean  $\pm$  SEM) of *Linomyza huidobrensis* mines on beans in monoculture, intercropped with tomato (high-risk), and intercropped with husk tomato (low-risk), at 9 weeks after planting.

|                     |      |       |      |   |
|---------------------|------|-------|------|---|
| Monoculture         | 9.57 | $\pm$ | 1.04 | a |
| Low-risk intercrop  | 6.13 | $\pm$ | 0.70 | b |
| High-risk intercrop | 5.43 | $\pm$ | 0.68 | b |

Treatment means followed by the same letter are not significantly different at  $\alpha=0.05$  ( $n=6$ , ANOVA and Student-Newman-Keuls test performed on data transformed by  $\log_{10}(x+1)$ ).

Several species of aphids were sampled on both bean plants and secondary crops. Aphids are important vectors of several bean diseases, including bean yellow mosaic and bean common mosaic (Hall 1991). Intercrops have been found to reduce the landing rate of aphids on beans, as a result of providing greater ground cover than beans in monoculture (Bottenberg and Irwin 1992a, 1992b), but aphid populations in the current study did not exhibit a response to cropping system.

Flea beetles (*Chaetocnema* sp.) were observed on both bean and secondary crops. At 8 weeks after planting, their density on bean in the husk tomato intercrop was higher than in the 2 other treatments, and at 15 weeks after planting the same was true for the monoculture treatment. The seasonal mean densities did not differ, however (Tables 4-2 and 4-4).

Leafhoppers, particularly *Empoasca* sp., while present at low density during this study, are a potentially serious pest of bean. *E. kraemeri* (Ross and Moore) is considered the most important bean pest in Latin America, capable of severely reducing yields by causing leaf curling and stunting. The related

species *E. fabae* (Harris) has been described as a pest of beans in Central America (Cardona 1989). Population densities of *Empoasca* spp. have been reported elsewhere to be higher on bean grown in monoculture than in weedy cropping systems and those with cover crops (Schoonhoven et al. 1981; Andow 1992). Specifically, intercropping beans with tomato reduced population densities of *E. fabae* on bean by reducing feeding time on the plant (Roltsch and Gage 1990a, 1990b). This response was not observed in the present study; however, density of *Empoasca* sp. was not increased by the addition of tomato or husk tomato.

Table 4-4. Densities (mean no. per 0.4 m-row bean  $\pm$  SEM) of flea beetles (*Chaetocnema* sp. adults) on beans in monoculture, intercropped with tomato (high-risk), and intercropped with husk tomato (low-risk), at 9 and 15 weeks after planting.

|                     | 8 weeks after planting |            |   | 15 weeks after planting |            |   |
|---------------------|------------------------|------------|---|-------------------------|------------|---|
| Monoculture         | 0.00                   | $\pm$ 0.00 | b | 0.10                    | $\pm$ 0.06 | a |
| High-risk intercrop | 0.00                   | $\pm$ 0.00 | b | 0.00                    | $\pm$ 0.00 | b |
| Low-risk intercrop  | 0.13                   | $\pm$ 0.06 | a | 0.00                    | $\pm$ 0.00 | b |

Treatment means followed by the same letter are not significantly different at  $\alpha=0.05$  ( $n=6$ , ANOVA and Student-Newman-Keuls test performed on data transformed by  $\log_{10}(x+1)$ ).

Whiteflies are also potentially serious pests of bean as a result of their role in virus transmission. *B. tabaci* is a vector of bean golden mosaic, which is common in Central America, especially where tomatoes are grown in proximity to beans (Hall 1991). Population densities of *B. tabaci* on beans remained low throughout the study, probably because of the high altitude of the study area.

The bean leafroller (*U. proteus*), is considered a minor pest of beans, requiring more than 4 fifth-instar larvae per plant to cause yield reductions (Cardona 1989). Its density was very low throughout the experiment and was no different among treatments.

The leaf beetle genera *Cerotoma* and *Diabrotica* constitute the most important chrysomelids on bean in many parts of Latin America (Cardona et al. 1982). Not only do they incur damage by defoliation and root feeding, but they are also vectors of several bean viruses, including bean curly dwarf mosaic, bean mild mosaic and bean rugose mosaic, all of which are present in Central America (Hall 1991). Defoliation damage has been determined to be more detrimental to the plant during the early growth and flowering stages, reaching 60% defoliation when 2-4 beetles were present per plant (Cardona et al. 1982). In the present experiment, population densities of these beetles remained low and were not affected by cropping system.

*Cerotoma* and *Diabrotica* larvae are found in soil, and while *Diabrotica balteata* larvae feed primarily on roots of grasses (Krysan 1986), larvae of some species of *Cerotoma* develop on bean (González et al. 1982). However, the only pest insect found in soil was *Phyllophaga* sp. (white grubs), occurring at the same low density for all treatments.

#### Beneficial Insect Populations on Bean

Biological control through conservation of natural enemies entails the maintenance of beneficial populations in the agroecosystem, particularly by

adjusting pesticide applications for optimum protection of beneficials (Hoy 1988). In the small-scale cropping systems studied here, conservation of natural enemies can be a key element of pest management. Sampling in the absence of disruptive control tactics to determine beneficial insects present in the agroecosystem is instrumental in ascertaining the degree of potential natural control in each cropping system.

Although several beneficial insect groups were present during the season (Table 4-5), most were not abundant enough to quantify throughout the experiment. One exception was the coccinellid *Brachiacantha lepida* Mulsant, whose population density was not affected by intercropping with either tomato or husk tomato. The potential for natural control was not diminished by intercropping beans with either tomato or husk tomato, and the addition of these crops to the agroecosystem may provide additional resources to parasitoids and predators.

### Bean Diseases

Despite the presence of several virus vectors (*Empoasca* sp., leafhoppers, the chrysomelid beetles *D. balteata* and *Cerotoma* spp, aphids, and the whitefly *B. tabaci*) on beans throughout the experiment, no virus was detected from samples of beans in any treatment. Fungal diseases were found, however, on foliage (bean rust, *U. phaseoli*, powdery mildew (*Erysiphe polygoni* DC), and an unidentified leaf spot), on pods (anthracnose, *Colletotrichum lindemuthianum* (Sacc. & Magn.) Briosi & Cav.), and on roots (*Rhizoctonia* sp.).



Table 4-5. Insect natural enemies collected in bean-based cropping systems.

| Order       | Family         | Sub-family, genus or species              | Crop (Host)                            |
|-------------|----------------|-------------------------------------------|----------------------------------------|
| Hemiptera   | Nabidae        | <i>Nabis</i> sp.                          | Bean, Tomato                           |
|             | Anthocoridae   | <i>Lasiochilus</i> sp.                    | Bean                                   |
|             |                | <i>Onus</i> sp.                           | Bean                                   |
| Neuroptera  | Hemerobiidae   | <i>Hemerobius</i> sp.                     | Bean                                   |
| Coleoptera  | Coccinellidae  | <i>Brachiacantha lepida</i>               | Bean                                   |
|             |                | Mulsant                                   |                                        |
|             |                | <i>Cycloneda sanguinea sanguinea</i> (L.) | Bean, husk tomato                      |
|             |                | <i>Psyllobora vigintimaculata</i> (Say)   | Husk tomato                            |
| Hymenoptera | Braconidae     | <i>Cotesia</i> sp.                        | Bean ( <i>Urbanus proteus</i> )        |
|             | Aphidiidae     | <i>Aphidius</i> sp. 3                     | Bean                                   |
|             |                | <i>Trioxys</i> sp.                        | Bean                                   |
|             | Ichneumonidae  | <i>Casinarina</i> sp.                     | Husk tomato                            |
|             |                | <i>Chiloplatys</i> sp.                    | Bean                                   |
|             |                | <i>Mesochorus</i> sp.                     | Bean                                   |
|             |                | <i>Exetastes</i> sp.                      | Cilantro                               |
|             | Eulophidae     | <i>Idiolispa</i> sp.                      | Bean (spider eggs)                     |
|             |                | Eulophinae undet. sp.                     | Bean ( <i>Liriomyza huidobrensis</i> ) |
|             | Diapriidae     | <i>Trichopria</i> sp.                     | Bean                                   |
|             | Platygastridae | <i>Bramesius</i> sp.                      | Bean                                   |
|             |                | <i>Synopeas</i> sp.                       | Bean                                   |

While disease problems on beans in the area can be extreme during the rainy season, incidence of all disease on beans was low for most of this experiment, increasing only during the final weeks before harvest. Powdery mildew and anthracnose were observed so infrequently that their presence was not quantified. Also, there were no differences in disease incidence among cropping systems, with the exception that for the last sampling date (15 weeks after planting) a lower percentage of plants was infested with rust in the husk tomato intercrop than the other two treatments (Table 4-6).

Table 4-6. Percentage of bean plants infested with rust (*Uromyces phaseoli* (Reben) Wint), in monoculture, intercropped with tomato (high-risk), and intercropped with husk tomato (low-risk), at 15 weeks after planting (mean  $\pm$  SEM).

|                     |       |       |      |   |
|---------------------|-------|-------|------|---|
| Monoculture         | 70.68 | $\pm$ | 5.90 | a |
| High-risk intercrop | 68.62 | $\pm$ | 6.15 | a |
| Low-risk intercrop  | 43.37 | $\pm$ | 6.46 | b |

Treatment means followed by the same letter are not significantly different at  $\alpha=0.05$  ( $n=6$ , ANOVA and Student-Newman-Keuls test performed on data transformed by square root).

Boudreau and Mundt (1992, 1994) examined the effects of intercropping corn with beans on the development of bean rust, concluding that where the intercrop resulted in reduced severity of rust, microclimatic changes produced by the corn plant were probably responsible. Disease severity was not estimated in the present experiment but was consistently low. The husk tomato plants were larger by the end of the season than the tomato plants, and that may have

hindered spread of the disease in the husk tomato treatments. Overall, there was virtually no influence of cropping system on disease development in bean.

### Damage to Bean

Population densities of pest insects sampled were low during the experiment, but pest densities may be low and still inflict considerable damage, or the sampling scheme may not reflect all population densities accurately. Consequently, to confirm the effects of insect pests on the 3 cropping systems, roots, foliage and beans were all examined during the season for damage.

Root development was the same for all cropping systems, with only 1 exception (root width at 4 weeks after planting was higher in the low-risk intercrop) (Table 4-7). The general similarity in root development among treatments suggests that roots were not being damaged differentially among the cropping systems.

The most important defoliators on bean during the experiment were the chrysomelid beetles *D. balteata*, *Cerotoma atrofasciata* and *C. ruficornis*. The sampling method of direct counts for *D. balteata* populations may not be very effective (Chiang Lok et al. 1986), and since defoliation was observed at low beetle numbers, percent defoliation on bean plants was measured to verify the effects of these beetles. There were no differences among cropping systems on any sampling date (Figure 4-2), confirming that the intercrops did not increase the damage from this pest group on bean. Furthermore, mean percent defoliation never exceeded 7%. In a study of the effect of defoliation from

Table 4-7. Mean root system width, length and weight ( $\pm$  SEM) of black beans in monoculture and intercropped with tomato (high-risk intercrop), and husk tomato (low-risk intercrop) during the dry season of 1997.

|                         | Root width (cm)<br>Mean $\pm$ SEM | Root length (cm)<br>Mean $\pm$ SEM | Root weight (g)<br>Mean $\pm$ SEM |
|-------------------------|-----------------------------------|------------------------------------|-----------------------------------|
| 4 weeks after planting  |                                   |                                    |                                   |
| Monoculture             | 1.64 $\pm$ 0.31 b                 | 7.69 $\pm$ 1.06 a                  | 0.21 $\pm$ 0.02 a                 |
| High-risk intercrop     | 0.93 $\pm$ 0.23 b                 | 6.14 $\pm$ 0.96 a                  | 0.18 $\pm$ 0.02 a                 |
| Low-risk intercrop      | 3.57 $\pm$ 0.69 a                 | 5.84 $\pm$ 0.49 a                  | 0.22 $\pm$ 0.04 a                 |
| 6 weeks after planting  |                                   |                                    |                                   |
| Monoculture             | 3.08 $\pm$ 0.38 a                 | 10.69 $\pm$ 1.00 a                 | 1.56 $\pm$ 0.09 a                 |
| High-risk intercrop     | 3.39 $\pm$ 0.39 a                 | 11.78 $\pm$ 0.75 a                 | 1.87 $\pm$ 0.13 a                 |
| Low-risk intercrop      | 3.33 $\pm$ 0.37 a                 | 11.64 $\pm$ 0.76 a                 | 1.77 $\pm$ 0.15 a                 |
| 8 weeks after planting  |                                   |                                    |                                   |
| Monoculture             | 4.82 $\pm$ 0.41 a                 | 13.47 $\pm$ 0.96 a                 | 1.59 $\pm$ 0.20 a                 |
| High-risk intercrop     | 4.58 $\pm$ 0.28 a                 | 12.77 $\pm$ 0.66 a                 | 1.63 $\pm$ 0.18 a                 |
| Low-risk intercrop      | 5.10 $\pm$ 0.43 a                 | 14.08 $\pm$ 0.75 a                 | 1.63 $\pm$ 0.14 a                 |
| 10 weeks after planting |                                   |                                    |                                   |
| Monoculture             | 7.36 $\pm$ 0.59 a                 | 16.06 $\pm$ 0.65 a                 | 2.66 $\pm$ 0.38 a                 |
| High-risk intercrop     | 7.46 $\pm$ 0.57 a                 | 15.22 $\pm$ 0.68 a                 | 2.19 $\pm$ 0.22 a                 |
| Low-risk intercrop      | 6.82 $\pm$ 0.63 a                 | 15.59 $\pm$ 0.73 a                 | 2.39 $\pm$ 0.33 a                 |
| 12 Weeks After Planting |                                   |                                    |                                   |
| Monoculture             | 9.70 $\pm$ 0.71 a                 | 18.90 $\pm$ 0.66 a                 | 3.59 $\pm$ 0.48 a                 |
| High-risk intercrop     | 8.08 $\pm$ 0.68 a                 | 17.22 $\pm$ 0.66 a                 | 3.18 $\pm$ 0.35 a                 |
| Low-risk intercrop      | 10.09 $\pm$ 0.75 a                | 17.68 $\pm$ 0.78 a                 | 3.14 $\pm$ 0.36 a                 |
| 14 Weeks After Planting |                                   |                                    |                                   |
| Monoculture             | 11.18 $\pm$ 0.79 a                | 17.78 $\pm$ 0.75 a                 | 3.66 $\pm$ 0.38 a                 |
| High-risk intercrop     | 10.58 $\pm$ 0.79 a                | 17.79 $\pm$ 0.72 a                 | 3.75 $\pm$ 0.44 a                 |
| Low-risk intercrop      | 10.28 $\pm$ 0.67 a                | 18.62 $\pm$ 0.79 a                 | 3.70 $\pm$ 0.36 a                 |

Treatment means for each measurement and date followed by the same letter are not significantly different at  $\alpha=0.05$  ( $n=6$ , Student-Newman-Keuls test used to separate means where differences detected).

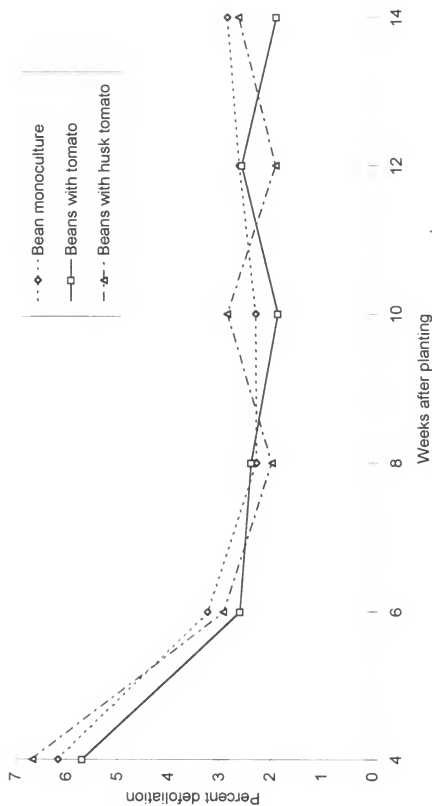


Figure 4-2. Mean percent defoliation from Chrysomelid beetles (*Cerotoma* spp. and *Diabrotica balteata* adults) on black beans in monoculture, intercropped with tomato, and intercropped with husk tomato, during the dry season of 1997. No significant differences among treatments were detected for any sampling date (alpha=0.05, n=6, ANOVA and Student-Newman-Keuls test performed on data transformed by square root).

Mexican bean beetle, Capinera et al. (1987) determined that less than 19% foliage loss did not affect the yield of *P. vulgaris*.

In terms of other damage, no differences were seen among treatments, either for development of pods or beans within pods, or in percentage of beans damaged by insects, disease (anthracnose) or rats (Table 4-8). Overall damage was low, with less than 2% of beans exhibiting signs of insect damage and less than 1% of anthracnose or rat damage.

#### Insects and Diseases on Secondary Crops

Insects were not a significant source of damage on either tomato or husk tomato plants in these cropping systems. *H. zea* larvae were the principal cause of insect damage on tomato plants, with 2.63% of harvested fruits damaged and 0.24% with presence of larvae. Although tomato in monoculture was not included as a treatment, the tomato and bean intercrop has been shown elsewhere to significantly reduce damage of major pests on tomato, particularly *Heliothis* spp., *Spodoptera* spp. and *Liriomyza sativae* Blanchard, the first 2 by as much as 90% (Rosset et al. 1987). Flea beetles (*Chaetocnema* spp. and *Strabala* sp.) were the most common insects observed on husk tomato, but were also not abundant enough to inflict substantial damage. Insects collected occasionally on these crops are given in Tables 4-1 and 4-5.

Damage to tomato from disease was much more consequential. Fifteen percent of tomato fruits at harvest had blemishes as a result of late blight (*Phytophthora infestans* (Mont.) d By), while 2.5% showed signs of early blight

Table 4-8. Development and damage of bean in monoculture, bean intercropped with tomato, and bean intercropped with husk tomato (mean  $\pm$  SEM), at harvest (21 April 1997).

|                     | No. pods/plant   |  | No. beans/pod   |  | Percent of beans not developed |  |
|---------------------|------------------|--|-----------------|--|--------------------------------|--|
|                     | Mean $\pm$ SEM   |  | Mean $\pm$ SEM  |  | Mean $\pm$ SEM                 |  |
| Bean monoculture    | 17.47 $\pm$ 2.25 |  | 4.68 $\pm$ 0.12 |  | 6.76 $\pm$ 1.18                |  |
| Beans + tomato      | 16.60 $\pm$ 1.63 |  | 4.71 $\pm$ 0.11 |  | 8.15 $\pm$ 1.10                |  |
| Beans + husk tomato | 13.95 $\pm$ 1.23 |  | 4.68 $\pm$ 0.13 |  | 7.90 $\pm$ 0.88                |  |

|                     | Percent of beans with insect damage |  | Percent of beans with anthracnose |  | Percent of beans with rat damage |  |
|---------------------|-------------------------------------|--|-----------------------------------|--|----------------------------------|--|
|                     | Mean $\pm$ SEM                      |  | Mean $\pm$ SEM                    |  | Mean $\pm$ SEM                   |  |
| Bean monoculture    | 1.38 $\pm$ 0.24                     |  | 0.15 $\pm$ 0.12                   |  | 0.05 $\pm$ 0.04                  |  |
| Beans + tomato      | 1.45 $\pm$ 0.24                     |  | 0.00 $\pm$ 0.00                   |  | 0.51 $\pm$ 0.28                  |  |
| Beans + husk tomato | 1.55 $\pm$ 0.39                     |  | 0.32 $\pm$ 0.19                   |  | 0.56 $\pm$ 0.37                  |  |

No significant differences among treatments were detected for any measurement ( $\alpha=0.05$ ,  $n=6$ , ANOVA and Student-Newman-Keuls test performed on data transformed by square root (percents) or  $\log_{10}(x+1)$  (no. pods/plant and no. beans/pod)).

(*Alternaria solani* (Ell. & G. Martin) Sor.). However, the effects of these diseases on yield were more evident in the number of fruits too small for consumption (34.7%). By harvest, nearly 100% of plants were infested with early blight, late blight, or both, and the reduced yields resulting from fewer fruits and small fruit size was evident. As a result, disease control was necessary in this cropping system. Given that the prevalent control for tomato diseases in the area is chemical, the cropping system incorporating tomato into black bean cultivation (high-risk intercrop) would probably result in greater amounts of chemical pesticides being used. This would have negative consequences for the conservation of beneficial insect populations and for the health of the farm family.

On the other hand, husk tomato was relatively free of disease, with only occasional plants showing symptoms of powdery mildew (*Oidium* sp.). The low-risk treatment would not require insect or disease control, and from this point of view is preferable to the high-risk treatment for small-scale farmers in the area.

### Conclusions

When designing more intensive intercropping systems for small-scale farmers, it is important to determine if crops associated for reasons other than plant protection may actually increase the need for pest management. In the current study, seasonal mean densities of insects on bean were not affected by cropping system. When sampling dates were analyzed individually, there were only 3 instances of differences in pest densities, once for mines of the leafminer



*L. huidobrensis* and on 2 dates for the flea beetle *Chaetocnema* sp. On 2 of these 3 occasions, the mean density in the bean monoculture was significantly higher than that of the intercrops, and the only occasion when a pest density in one of the intercrops (beans with husk tomato) was higher was relatively early in the season. In addition, population densities of all insect pests sampled were relatively low throughout the season. Thus, densities of the most abundant pest species were not affected by the addition of these particular crops to beans.

In addition to establishing that bean pest population densities were no higher in either intercrop than in the bean alone, this study has shown that beneficial populations on bean were no lower in either intercrop, bean diseases were no greater in either intercrop, and damage was no more prevalent in either intercrop. Consequently, the addition of either tomato or husk tomato to the bean cropping system would not increase the need for pest management on bean.

However, the high-risk treatment of beans with tomato requires additional pest management for tomato diseases, while the low-risk treatment of bean with husk tomato does not require such management. Since neither intercrop affects pests or damage on the staple crop bean, they are both advantageous over the bean monoculture, but the additional pest management required for tomato makes that alternative less viable than the husk tomato intercrop, which had very low levels of insect and disease pests. For the group of farmers in the study area, the bean and husk tomato intercrop is preferable, when evaluated on the basis of pest management.

## CHAPTER 5 NEMATODE POPULATION DENSITIES IN ALTERNATIVE CORN- AND BEAN- BASED CROPPING SYSTEMS

### Introduction

Although the effects of nematodes on agricultural systems have been studied less frequently in tropical areas, in many cases they may be more severe in those areas due to greater population build-up as a result of higher temperatures and more intensive annual cropping cycles. Worldwide crop losses as a result of nematode damage have been estimated at around 5%, while for some small-scale farmers in tropical areas, losses may reach as high as 25-50% (Taylor and Sasser 1978). The lack of information on nematode populations in tropical regions makes nematode control particularly difficult for small-scale farmers for whom nematodes remain more obscure than other types of agricultural pests.

In Central America, chemical control of nematodes is generally not economically feasible for small-scale farmers, and economic thresholds are difficult to establish (Sosa-Moss 1985, Pinochet 1987). Many traditional agricultural systems worldwide prevent nematode population build-up through the maintenance of plant genetic diversity and the selection of tolerance or resistance in host plants, which does not require farmer understanding of specific nematode populations (Page and Bridge 1993).

Similarly, the continuous presence of susceptible hosts can be avoided by crop rotations, long promoted as one of the most effective nematode management tactics (Noe et al. 1991, Nusbaum and Ferris 1973) and particularly suited to the needs of low-resource farmers in the tropics (Noe 1988). The primary objective of crop rotation is to reduce the initial nematode population density by the presence of a non-host or poor host, to such an extent that the following susceptible crop is able to complete its development before nematode population densities build up enough to inflict significant damage. A secondary objective is to diversify the soil community, promoting natural control of nematode pest species (Trivedi and Barker 1986).

While crop rotation has been shown to be a successful management strategy in certain situations for *Heterodera* spp., *Ditylenchus* spp., *Belonolaimus* spp. and *Pratylenchus* spp. (Trivedi and Barker 1986), most rotation studies have focused on populations of root-knot nematodes (*Meloidogyne* spp.), because of their worldwide importance as agricultural pests. Rotation for the control of *Meloidogyne* spp. is complicated by the wide host ranges of these nematodes, and screening for susceptibility of crop cultivars must be done for various species and races, which may occur in mixed populations (Barker and Noe, 1987).

Rotation crops have been tested for their effects on reducing *Meloidogyne* spp. numbers and increasing yields in peanut (*Arachis hypogaea* L.) (Rodríguez-Kábana et al. 1988b, 1991a), soybean (*Glycine max* Merr.) (Rodríguez-Kábana et al. 1990b, 1991b; Weaver et al. 1988, Minton and Bondari 1994), tobacco

(*Nicotiana tabacum* L.) (Fortnum and Currin 1993), and vegetable crops (McSorley et al. 1994b, 1994c). Furthermore, there has been increasing interest in evaluating tropical crops for their susceptibility to nematodes, to aid in the design of rotation systems (McSorley et al. 1994a; Gallaher and McSorley 1993, Hutton et al. 1983, Rodríguez-Kábana et al. 1990). Although there is increasing understanding of nematode population response to sequential crop arrangements that include non-host or poor host crops, the effects of adding such crops in a spatial dimension are not as clear. As has been found for insect pests, intercropping studies have shown variable effects on nematode population densities, which is not surprising, given the range of environmental factors and interactions with other organisms responsible for changes in nematode population densities.

Raymundo (1985) cites several examples of reduced damage from *Meloidogyne incognita* (Kofoid and White) when susceptible crops are grown in association with non-susceptible plants, including a reduction in root galls on potato from the addition of onion and corn, and the potential for intercropping with marigold (*Tagetes* spp.) for its possible nematicidal effects. Tomato plants also have been found to have reduced numbers of galls and lower root populations of *M. incognita* and *Pratylenchus alleni* Ferris when intercropped with castor bean (*Ricinus communis* L.), marigold, or chrysanthemum (Hackney and Dickerson 1975), and similar reduction in galls on tomato were reported with the legume intercrops *Pueraria phaseoloides* (Roxb.) Benth. and *Arachis pintoi*

Krap. et Greg. nom. nud., although several other legumes tested did not influence galling on tomato (Marban-Mendoza et al. 1992).

*M. incognita* populations have been shown to be adversely affected by an intercrop of sesame (*Sesamum orientale* L.) and okra (*Abelmoschus esculentus* L. (Moench.)), with both showing higher yields than in their respective monocultures (Tanda and Atwal 1988). In a study of several spatial and temporal mixes of tropical crops in India, Sharma et al. (1996) found that responses of *Heterodera cajani* Koshy, *Helicotylenchus retusus*, and *Rotylenchus reniformis* Linford Oliviera were influenced more by previous crops than by intercrops. The results also suggested that an intercrop of a pigeonpea (*Cajanus cajan* (L.) Millsp.) tolerant to *H. cajani* with the non-host sorghum (*Sorghum bicolor* (L.) Moench) would be most effective in increasing productivity of traditional cropping systems where *H. cajani* is prevalent.

On the other hand, Powers et al. (1993) reported no effect on plant parasitic nematode densities of intercropping alfalfa (*Medicago sativa* L.) or hairy indigo (*Indigofera hirsuta* L.) with squash (*Cucurbita pepo* L.) or cucumber (*Cucumis sativa* L.), neither of which experienced lower nematode densities when intercropped with marigold (*Tagetes patula* L.). Alfalfa and crested wheatgrass (*Agropyron cristatum* (L.) Gaertner) in association also failed to exert an effect on *Pratylenchus neglectus* (Rensch) Filipjev & Schuurmans Stekhoven densities compared to their respective monocultures, when tested in an intercrop designed to improve soil fertility on rangelands (Griffin and Jensen 1997). The variable results found in these and other studies highlight the

importance of evaluating the specific cropping system under consideration to determine possible changes in nematode population densities and subsequent consequences for crop damage. Such evaluations are particularly important when additional crops are added to the system for purposes other than pest management. Given the tendency of small-scale farmers in the tropics to adapt cropping systems based on economic value, food stability and cultural traditions (Beets 1982), rather than considerations of plant protection from pests, information pertinent to nematode management in such cropping systems is essential.

In seeking more intensive cropping systems to meet small-scale farmers' changing economic and sociological conditions in the western Guatemalan highlands, nematode population densities in corn and black bean monocultures were compared to those in selected intercrops of each. The principal objective was to determine if adding certain crops to corn and beans would increase the need for actively managing nematodes. Since small-scale farmers in the area were found to be limited in their pest management capabilities, any effective alternative cropping systems would have to incur equal or lower pest damage than the present cropping systems.

### Methods and Materials

The field site, experimental design and plot layout are described in Chapter 3. Nematodes were sampled between May 1996 and April 1997, before and after both the corn and bean crops. Treatments were as described earlier

(Treatment 1 = corn monoculture followed by black bean monoculture; Treatment 2 = corn, black beans, broccoli and faba beans followed by black beans and tomatoes; Treatment 3 = corn, black beans, cilantro, and amaranth followed by black beans and husk tomato), and agronomic management of all crops is described in Chapters 3 and 4.

Nematodes were sampled four times during the year, for initial population densities ( $P_i$ ) after plots were prepared but before planting (10 May 1996), at mid-season of the corn (9 September 1996), after the corn was harvested and before beans were planted (6 December 1996), and for final population densities ( $P_f$ ) after the bean harvest (21 April 1997). Soil samples, allocated systematically within each plot, were taken within the root zone of the corn and later the bean crops. Samples consisted of 12 cores per plot, of 2.5 cm-diameter and 15-20 cm depth, removed with a soil corer.

For each plot, cores were combined and a subsample of 100 cm<sup>3</sup> was taken for nematode extraction by a combined sieving and Baermann technique (Christie and Perry 1951). The subsample was suspended in water and passed through a coarse sieve, then placed on a 400 mesh sieve. The concentrated sample was placed on a tissue paper (Kimwipe®) in a modified Baermann setup consisting of a plastic electrical gang cover with wire screening set in a plastic sandwich dish filled with water to the level of the screening. After 48 hours (at a temperature of 17-22 °C), the water and nematode mixture was concentrated with a 400 mesh sieve. Nematodes were killed by heating in a 60 °C waterbath for 15 minutes and preserved in 10% formalin.

Nematodes were counted by genus and assigned to trophic groups according to Yeates et al. (1993). For the most prevalent genera and for trophic groups, initial and final population densities of the 3 treatments were compared for both the corn and bean cycles of the experiment, as were the ratios of final to initial population densities for the corn cycle, bean cycle and total for the year.  $P_i/P_f$  ratios are based on values to which 0.01 was added to avoid division by zero, because in some cases initial population densities were too low to be detected. Analysis of Variance was performed on nematode count data transformed by  $\log_{10}(x+1)$ , using the PROC GLM procedure of SAS (SAS Institute 1990), and the Student-Newman-Keuls test was used to separate means when significant treatment differences were detected at  $\alpha = 0.05$ . Although transformed counts were used to determine treatment differences, tables reporting treatment means are of untransformed data.

## Results and Discussion

### Plant Parasitic Community

The principal genera of plant parasitic nematodes that were found in the cropping systems under study are shown in Table 5-1. Plant parasitic genera found occasionally include *Criconeoides*, *Paratylenchus* and *Scutellonema*. The genus *Psilenchus*, for which food habits are unclear, was also found occasionally and included with the plant parasites to which it is closely related.

While the population densities of some genera of plant parasitic nematodes declined over the corn cycle in some cropping systems, population



Table 5-1. Ratio of final to initial nematode population densities ( $P_f/P_i$ ) by genus from 100 cm<sup>3</sup> soil samples taken from monocultures (corn followed by beans) and two alternative intercrops (high-risk intercrop of corn with black beans, faba beans and broccoli, followed by black beans with tomato, and low-risk intercrop of corn with black beans, cilantro and amaranth, followed by black beans with husk tomato).

|                         | Corn cycle         |         | Bean cycle         |          | Total for year     |          |
|-------------------------|--------------------|---------|--------------------|----------|--------------------|----------|
|                         | Mean $P_f/P_i \pm$ | SE      | Mean $P_f/P_i \pm$ | SE       | Mean $P_f/P_i \pm$ | SE       |
| <i>Meloidogyne</i>      |                    |         |                    |          |                    |          |
| Monoculture             | 0.65 $\pm$         | 0.21 a  | 11.74 $\pm$        | 9.73 a   | 2.51 $\pm$         | 1.53 a   |
| High-risk intercrop     | 0.34 $\pm$         | 0.15 a  | 187.08 $\pm$       | 182.79 a | 3.25 $\pm$         | 1.79 a   |
| Low-risk intercrop      | 0.46 $\pm$         | 0.36 a  | 6.60 $\pm$         | 3.41 a   | 0.94 $\pm$         | 0.39 a   |
| <i>Helicotylenchus</i>  |                    |         |                    |          |                    |          |
| Monoculture             | 4.95 $\pm$         | 1.95 a  | 167.65 $\pm$       | 166.67 a | 6.16 $\pm$         | 1.88 a   |
| High-risk intercrop     | 68.47 $\pm$        | 66.51 a | 4.04 $\pm$         | 1.50 a   | 537.63 $\pm$       | 532.68 a |
| Low-risk intercrop      | 1.78 $\pm$         | 0.72 a  | 2.89 $\pm$         | 1.07 a   | 2.99 $\pm$         | 0.82 a   |
| <i>Pratylenchus</i>     |                    |         |                    |          |                    |          |
| Monoculture             | 83.87 $\pm$        | 83.43 a | 67.76 $\pm$        | 66.65 a  | 51.04 $\pm$        | 49.99 a  |
| High-risk intercrop     | 0.95 $\pm$         | 0.62 a  | 270.57 $\pm$       | 153.21 a | 28.71 $\pm$        | 16.97 a  |
| Low-risk intercrop      | 50.94 $\pm$        | 50.01 a | 138.50 $\pm$       | 70.06 a  | 43.10 $\pm$        | 20.01 a  |
| <i>Trichodorus</i>      |                    |         |                    |          |                    |          |
| Monoculture             | 35.08 $\pm$        | 20.85 a | 367.81 $\pm$       | 172.50 a | 335.00 $\pm$       | 166.40 a |
| High-risk intercrop     | 1.82 $\pm$         | 1.13 a  | 300.88 $\pm$       | 262.07 a | 4.63 $\pm$         | 2.37 b   |
| Low-risk intercrop      | 36.11 $\pm$        | 20.60 a | 152.20 $\pm$       | 149.76 a | 94.11 $\pm$        | 51.91 ab |
| <i>Hemicycliophora</i>  |                    |         |                    |          |                    |          |
| Monoculture             | 0.75 $\pm$         | 0.17 a  | 84.25 $\pm$        | 30.78 a  | 67.42 $\pm$        | 33.43 a  |
| High-risk intercrop     | 84.17 $\pm$        | 54.31 a | 67.45 $\pm$        | 49.50 a  | 100.83 $\pm$       | 51.70 a  |
| Low-risk intercrop      | 34.50 $\pm$        | 33.30 a | 50.67 $\pm$        | 22.51 a  | 50.67 $\pm$        | 22.51 a  |
| <i>Tylenchorhynchus</i> |                    |         |                    |          |                    |          |
| Monoculture             | 1.22 $\pm$         | 0.37 a  | 54.36 $\pm$        | 49.37 b  | 7.44 $\pm$         | 4.50 a   |
| High-risk intercrop     | 17.00 $\pm$        | 16.80 a | 917.50 $\pm$       | 415.14 a | 38.68 $\pm$        | 32.69 a  |
| Low-risk intercrop      | 0.26 $\pm$         | 0.17 a  | 953.31 $\pm$       | 446.05 a | 504.47 $\pm$       | 499.31 a |

Samples taken in May 1996 (corn  $P_i$  and total  $P_i$ ), December 1996 (corn  $P_f$  and bean  $P_i$ ), and April 1997 (bean  $P_f$  and total  $P_f$ ). For all mean values,  $n=6$ . Treatment means within cropping cycle and genus followed by the same letter are not significantly different ( $\alpha=0.05$ , ANOVA and Student-Newman-Keuls test performed on data transformed by  $\log_{10}(x+1)$  after 0.01 added to avoid division by zero).

densities of all principal plant parasites increased during the bean cycle ( $P/P_i > 1$ ). This contributed to an increase over the year in all but populations of *Meloidogyne* spp. This genus constituted 54% of the plant parasitic nematodes at the start of the experiment ( $P_i$ ) and only 17% at the end of the corn cycle, increasing again during the bean cycle to 29% of the total. In contrast, 23% of plant parasites were *Helicotylenchus* spp. at  $P_i$ , increasing to 58% after the corn cycle and decreasing to 32% by the end of bean cycle. The relative composition of the plant parasitic nematode community remained fairly constant for the remaining genera.

During the corn cycle, there were no significant differences among cropping systems for either  $P_i$  or  $P_f$  of any of the principal plant parasitic genera, and soil densities of all plant parasitic nematodes remained below 25 per 100  $\text{cm}^3$ . The reproductive rate ( $P/P_i$ ) also did not differ by cropping system for any of the principal genera during the corn cycle (Table 5-1).

Among the nematode genera able to reproduce on corn, the most commonly encountered include *Meloidogyne* and *Pratylenchus*, while *Trichodorus* spp. are among the most potentially destructive (Shurtleff 1980). In this experiment, during the corn cycle, the population density of *Meloidogyne* spp. remained below damage thresholds established for several species, the lower range of which starts at 50 nematodes/100  $\text{cm}^3$  soil (Barker et al. 1985). In fact, corn did not support reproduction of *Meloidogyne* spp. in any cropping system studied ( $P/P_i < 1$  for all treatments). While in some cases densities of *Meloidogyne* spp. have not increased significantly on corn (Kinloch 1983, Hutton

et al. 1983), in many instances corn has been found to be a suitable host (Gallaher et al. 1991, Sumner et al. 1985, Heffes et al. 1992). Since corn exhibits varied susceptibility to *Meloidogyne* spp., depending on cultivar and nematode species and race, local corn cultivars must be evaluated for susceptibility. Local corn used in the current study was a poor host, and the crops added to the system did not affect *Meloidogyne* spp. densities. *M. arenaria* and *M. incognita* have been observed to reproduce poorly on *A. cruentus* (Rodríguez-Kábana 1988a), so although germination of amaranth was low in the study, it would not be likely to increase *Meloidogyne* spp. populations in the cropping system treatment in which it was included, even under conditions of higher plant density.

*Pratylenchus* spp. nematodes are also common in soils in which corn has been grown, and *P. neglectus* has been shown to compete with *M. chitwoodi* on barley (*Hordeum vulgare* L.) and potatoes (Umesh and Ferris 1994). In the present study, however, mean densities of *Pratylenchus* spp. remained below 6 nematodes/100 cm<sup>3</sup> during the corn cycle and constituted no more than 9% of the plant parasitic nematodes extracted. Finally, populations of *Trichodorus* spp. can change rapidly and can be highly destructive to corn, but were not observed to rise beyond 4 nematodes/100 cm<sup>3</sup> during the corn cycle. The other plant parasitic nematodes recovered require high population densities to exert pathogenic effects on corn (Shurtleff 1980).

During the bean cycle, the only difference observed among treatments was in the final density ( $P_f$ ) of *Tylenchorhynchus* spp., which was higher in the

low-risk treatment (beans with husk tomato) than in the bean monoculture (Table 5-2). Subsequently, *Tylenchorhynchus* spp. showed a higher reproductive rate in both intercrop treatments than in the monoculture (Table 5-1). The great increase in *Tylenchorhynchus* spp. over the bean cycle resulted from its near absence (very low  $P_1$ ) prior to this crop. During the bean cycle, most genera had high reproductive rates across treatments. Since final population densities for no genus exceeded 35 nematodes per 100 cm<sup>3</sup> soil, low initial densities probably contributed to the high reproductive rates observed.

Table 5-2. Final densities (mean no. nematodes/100 cm<sup>3</sup> soil  $\pm$  SEM) of *Tylenchorhynchus* spp. from bean in monoculture, high-risk intercrop (beans with tomato), and low-risk intercrop (beans with husk tomato), April 1997.

|                     |       |       |      |    |
|---------------------|-------|-------|------|----|
| Low-risk intercrop  | 12.00 | $\pm$ | 4.09 | a  |
| High-risk intercrop | 9.17  | $\pm$ | 4.15 | ab |
| Monoculture         | 7.33  | $\pm$ | 4.62 | b  |

Treatment means followed by the same letter are not significantly different at  $\alpha=0.05$  ( $n=6$ , ANOVA and Student-Newman-Keuls test performed on data transformed by  $\log_{10}(x+1)$ ).

While *Tylenchorhynchus* has been found in association with the soil around bean roots, it is not considered to cause damage to the bean plant. In fact, among the nematodes at this site, *Meloidogyne* and *Pratylenchus* are the only two nematode genera with the potential to inflict substantial damage to bean. *P. penetrans* can reduce the growth of susceptible bean plants at a density of at least 50 nematodes/100 cm<sup>3</sup> soil (Hall 1991). Mean soil densities of these nematodes in the cropping systems examined were never greater than 30

per 100 cm<sup>3</sup>, despite the presence in the high-risk cropping system of tomato, generally an excellent host for *Meloidogyne* spp. (Jones et al. 1991).

### Total Nematode Community

*Tylenchus* (root associate), *Aphelenchus* (fungivore) and *Eucephalobus* (bacterivore) were among the most common genera of non-plant parasitic nematodes encountered. Additional fungivores included *Aphelenchoides* and *Nothotylenchus*, while the bacterivores *Monhystera*, *Plectus*, and *Wilsonema* were seen occasionally. The omnivores *Mesodorylaimus* and *Eudorylaimus* and the predators *Mononchus* and *Seinura* constituted the rest of the nematodes in the cropping systems examined.

The initial nematode community was dominated by plant parasites (mean of 45%), with 31% fungivores and 14% bacterivores. At the end of the corn cycle, plant parasites had decreased to 35%, with fungivores constituting 36% and bacterivores 17%. After the bean cycle, bacterivores were dominant (39%), and plant parasites accounted for only 29%. Fungivores comprised 24% of total nematodes at P<sub>f</sub>. Relative densities of omnivores and predators were 7-16% and 0.42-1.18%, respectively, during the year. The reduction in plant parasites and fungivores and increase in bacterivores over the year was consistent for all treatments. Even with overall increases in densities of plant parasitic genera during the bean cycle, plant parasites never constituted a high proportion of the total nematode community.

During the corn cycle, initial density of plant parasites in the low-risk treatment (corn with black beans, cilantro and amaranth) was higher than in the monoculture (Table 5-3), although by the end of that crop cycle, the mean population density of plant parasites had increased in the monoculture while decreasing in the other cropping systems (Table 5-4). Densities of fungivores and of total nematodes were initially lower in the corn monoculture, and by the end of the corn cycle, densities of bacterivores and omnivores in the monoculture were greater than in the other two treatments. No other significant differences in densities were observed for any sampling date. The reproductive rate for total nematodes was greater for the corn monoculture and high-risk intercrop (corn with black beans, broccoli and faba beans) than for the low-risk intercrop (corn with black beans, cilantro and amaranth) (Table 5-4).

Although initial densities of bacterivores and omnivores in the bean monoculture were higher than in the other two treatments, there were no differences in final densities for any trophic group. Furthermore, reproductive rate was not different among treatments for any trophic group in either the bean cycle or the total year (Table 5-4). For both genus and trophic group analyses, some mean  $P_f/P_i$  values are much higher than the mean  $P_f / \text{mean } P_i$ , due to addition of 0.01 to avoid division by zero, since several initial densities were zero.

Although very low initial densities for most genera and trophic groups contributed to high  $P_f/P_i$  values, the greatest population increase observed was 13-fold, an increase in bacterivore density in the high-risk intercrop (beans with

Table 5-3. Nematode densities (mean no. per 100 cm<sup>3</sup> soil  $\pm$  SEM) by trophic group for sampling dates with differences among cropping system treatments, taken from monocultures (corn followed by beans) and two alternative intercrops (high-risk intercrop of corn with black beans, faba beans and broccoli, followed by black beans with tomato, and low-risk intercrop of corn with black beans, cilantro and amaranth, followed by black beans with husk tomato).

|                                                                      |       |             |    |
|----------------------------------------------------------------------|-------|-------------|----|
| Plant parasites, May 1996 (P <sub>I</sub> )                          |       |             |    |
| Monoculture                                                          | 18.67 | $\pm$ 5.91  | b  |
| High-risk intercrop                                                  | 34.17 | $\pm$ 11.03 | ab |
| Low-risk intercrop                                                   | 38.17 | $\pm$ 5.72  | a  |
| Fungivores, May 1996 (P <sub>I</sub> )                               |       |             |    |
| Monoculture                                                          | 15.00 | $\pm$ 4.31  | b  |
| High-risk intercrop                                                  | 24.50 | $\pm$ 7.42  | a  |
| Low-risk intercrop                                                   | 23.83 | $\pm$ 4.03  | a  |
| Total nematodes, May 1996 (P <sub>I</sub> )                          |       |             |    |
| Monoculture                                                          | 48.33 | $\pm$ 16.57 | b  |
| High-risk intercrop                                                  | 78.00 | $\pm$ 27.86 | a  |
| Low-risk intercrop                                                   | 74.50 | $\pm$ 8.90  | a  |
| Bacterivores, Dec. 1996 (corn P <sub>r</sub> , bean P <sub>I</sub> ) |       |             |    |
| Monoculture                                                          | 21.83 | $\pm$ 4.72  | a  |
| High-risk intercrop                                                  | 8.92  | $\pm$ 5.25  | b  |
| Low-risk intercrop                                                   | 10.92 | $\pm$ 3.26  | b  |
| Omnivores, Dec. 1996 (corn P <sub>r</sub> , bean P <sub>I</sub> )    |       |             |    |
| Monoculture                                                          | 11.08 | $\pm$ 4.85  | a  |
| High-risk intercrop                                                  | 5.25  | $\pm$ 2.26  | b  |
| Low-risk intercrop                                                   | 4.75  | $\pm$ 1.08  | b  |

For all mean values, n=6. Treatment means within cropping cycle and trophic group followed by the same letter are not significantly different ( $\alpha=0.05$ , ANOVA and Student-Newman-Keuls test performed on data transformed by  $\log_{10}(x+1)$ ).

Table 5-4. Ratio of final to initial nematode population densities ( $P_f/P_i$ ) by trophic group from 100 cm<sup>3</sup> soil samples taken from monocultures (corn followed by beans) and two alternative intercrops (high-risk intercrop of corn with black beans, faba beans and broccoli, followed by black beans with tomato, and low-risk intercrop of corn with black beans, cilantro and amaranth, followed by black beans with husk tomato).

|                     | Corn cycle |                                      | Bean cycle |                                      | Total for year |                                      |
|---------------------|------------|--------------------------------------|------------|--------------------------------------|----------------|--------------------------------------|
|                     | Mean       | P <sub>f</sub> /P <sub>i</sub> ± SEM | Mean       | P <sub>f</sub> /P <sub>i</sub> ± SEM | Mean           | P <sub>f</sub> /P <sub>i</sub> ± SEM |
| Plant Parasites     |            |                                      |            |                                      |                |                                      |
| Monoculture         | 1.81 ±     | 0.99 a                               | 386.45 ±   | 382.92 a                             | 5.26 ±         | 1.70 a                               |
| High-risk intercrop | 0.72 ±     | 0.27 a                               | 5.37 ±     | 1.43 a                               | 3.33 ±         | 0.61 a                               |
| Low-risk intercrop  | 0.72 ±     | 0.25 a                               | 5.04 ±     | 2.33 a                               | 2.59 ±         | 1.20 a                               |
| Fungivores          |            |                                      |            |                                      |                |                                      |
| Monoculture         | 2.21 ±     | 0.71 a                               | 6.63 ±     | 3.89 a                               | 5.64 ±         | 2.09 a                               |
| High-risk intercrop | 1.48 ±     | 0.75 a                               | 7.15 ±     | 3.44 a                               | 4.19 ±         | 1.32 a                               |
| Low-risk intercrop  | 0.83 ±     | 0.28 a                               | 7.39 ±     | 2.28 a                               | 4.20 ±         | 1.42 a                               |
| Bacterivores        |            |                                      |            |                                      |                |                                      |
| Monoculture         | 220.61 ±   | 216.09 a                             | 4.25 ±     | 1.46 a                               | 1425.62 ±      | 1415.08 a                            |
| High-risk intercrop | 2.23 ±     | 0.84 a                               | 45.41 ±    | 32.89 a                              | 29.40 ±        | 9.21 a                               |
| Low-risk intercrop  | 2.53 ±     | 0.84 a                               | 12.26 ±    | 4.96 a                               | 25.53 ±        | 9.06 a                               |
| Omnivores           |            |                                      |            |                                      |                |                                      |
| Monoculture         | 502.04 ±   | 499.79 a                             | 2.83 ±     | 1.31 a                               | 652.62 ±       | 649.68 a                             |
| High-risk intercrop | 84.28 ±    | 83.35 a                              | 10.32 ±    | 4.64 a                               | 804.16 ±       | 799.37 a                             |
| Low-risk intercrop  | 1.05 ±     | 0.36 a                               | 320.34 ±   | 316.14 a                             | 6.58 ±         | 3.64 a                               |
| Predators           |            |                                      |            |                                      |                |                                      |
| Monoculture         | 84.17 ±    | 40.21 a                              | 67.34 ±    | 49.53 a                              | 100.92 ±       | 44.76 a                              |
| High-risk intercrop | 0.84 ±     | 0.17 a                               | 117.67 ±   | 47.73 a                              | 101.00 ±       | 51.64 a                              |
| Low-risk intercrop  | 117.17 ±   | 65.58 a                              | 83.96 ±    | 83.41 a                              | 34.66 ±        | 20.99 a                              |
| Total Nematodes     |            |                                      |            |                                      |                |                                      |
| Monoculture         | 2.67 ±     | 0.92 a                               | 3.45 ±     | 1.13 a                               | 6.74 ±         | 1.90 a                               |
| High-risk intercrop | 1.04 ±     | 0.40 a                               | 8.96 ±     | 3.20 a                               | 6.05 ±         | 1.58 a                               |
| Low-risk intercrop  | 0.83 ±     | 0.23 b                               | 7.17 ±     | 2.77 a                               | 4.11 ±         | 1.44 a                               |

Samples taken in May 1996 (corn  $P_i$  and total  $P_i$ ), December 1996 (corn  $P_f$  and bean  $P_i$ ), and April 1997 (bean  $P_f$  and total  $P_f$ ). For all mean values,  $n=6$ . Treatment means within cropping cycle and trophic group followed by the same letter are not significantly different ( $\alpha=0.05$ , ANOVA and Student-Newman-Keuls test performed on data transformed by  $\log_{10}(x+1)$  after 0.01 added to avoid division by zero).



tomato) during the bean cycle. However, the reproductive rate of bacterivores was not significantly different among treatments (Table 5-4). For all treatments, bacterivores increased in density more rapidly than any other trophic group during the bean cycle. Bactivoracious nematodes are important components of the soil biota, with a major role in decomposition and nutrient cycling, and as such are beneficial to crop plants present, particularly by increasing availability of nutrients (Freckman 1988).

### Conclusions

The present study sought to determine the effect on nematode population densities of adding selected intercrops to corn and beans. The additional crops were chosen for their potential economic and nutritional value and not for their value in suppressing pest populations. Therefore, it was unknown whether their inclusion in the cropping system would result in significantly higher nematode population densities that could lead to greater damage to the principal crops under the conditions of small-scale farmers in the study area. In assessing advantages and potential for acceptance of alternative cropping systems, it is important to determine whether the addition of particular crops may necessitate greater nematode management on the part of the farmer.

In the cropping systems tested, nematode densities either decreased or increased only slightly during the corn cycle, with consistent increases during the bean cycle. The decline in relative abundance of plant parasites and augmentation of bacterivorous nematodes in the study plots over the year illustrate

the favorable nature of the cropping systems tested in terms of effects on the nematode community.

Densities of all plant parasitic nematode populations remained low throughout the study, indicating the lack of need for nematode management. Furthermore, neither of the alternative cropping systems tested resulted in significant increases over the monoculture in terms of population densities of nematodes considered to be economically damaging in corn or beans. The results allow us to consider such cropping systems for their non-pest management merits, without concern of contributing to the difficulty farmers may encounter in managing pests as a result of their already limited information and capital.

## CHAPTER 6 ECONOMIC, ENERGETIC AND NUTRITIONAL RETURNS FROM ALTERNATIVE CORN- AND BEAN-BASED CROPPING SYSTEMS

### Introduction

For alternative cropping systems to be accepted by low-resource farmers in the tropics, they must be shown not only to not contribute to increased pest problems, but also to be more productive, providing apparent advantages to the farm family. Greater productivity can be realized through efficient utilization of available inputs, particularly land, labor, capital, and energy. Limits in arable land combined with growing demand for food impel more intensive use of available land (Stout 1990). Yield advantages have often been demonstrated in intercropping systems as a result of more efficient resource use by plants with complementary resource needs, specifically light, water and nutrients (Willey 1979). In some cases, intercrops may also provide enough relief from pest pressure to subsequently affect yields.

However, the resulting economic returns are of primary concern to the farm family and should be evaluated according to the aim of the intercropping system (i.e., yield stability, or maintenance of yield of main crop). For example, Brown et al. (1985) analyzed a vegetable intercropping system developed to maximize total productivity of two-vegetable combinations and found that at least one combination produced greater total yield and economic return per unit land

area. They concluded that the intercrop will be particularly advantageous when the market value of one crop declines or when land is scarce. Therefore, benefits to the farmer become apparent when alternative cropping systems are evaluated in terms of maximizing returns while minimizing the use of limited resources.

Usually, analyses of agricultural systems have taken an economic approach, centering solely on the objective of profit maximization, rather than an energetic approach, which focuses on minimizing energy inputs per unit of energy output in sustainable systems (Schahczenski 1984). The shift from hunting-gathering activities to early agriculture to modern production agriculture has taken place through more intensive management of the agroecosystem, primarily through growth in human and then fossil fuel energy inputs, the latter taking the form of fertilizers, pesticides, farm machinery and irrigation (Pimentel 1992). Energy analysis developed out of the rising energy prices of the 1970s and the realization that the high yields of industrialized agriculture were driven by non-renewable energy inputs that are limited. The improvement of energy efficiency subsequently became a goal of sustainable agriculture research.

Energy analysis has been applied to both industrialized agriculture (Franzleubbers and Francis 1995) and traditional agricultural systems (Dazhong and Pimentel 1984, Pandya and Pedhadiya 1993) to examine energetic self-sufficiency and improve efficiency of energy use. Measures of energy efficiency are often used to compare alternative production systems (for example, Berardi 1978, Gajaseni 1995, Nguyen and Haynes 1995, Sharma 1991; Sharma and

Sharma 1993, Vredevelde et al. 1983). Furthermore, traditional agricultural systems are often found to be highly energy efficient, and evaluations of their energetics can show us ways of improving the efficient utilization of local energy resources (Schahczenski 1984).

While efficiency of land and energy use and maximization of economic returns are all important goals in the design of alternative production systems, nutritional benefits should not be overlooked, particularly for small-scale farmers who consume much of the principal crop produced. It is important to determine the nutritional yields of each cropping system, because increases in income as a result of greater agricultural commercialization do not necessarily lead to improvements in the nutritional well being of farm families. Instead, nutritional quality is often related to dietary diversity, which tends to be higher for low-resource subsistence families than for those undergoing agricultural commercialization (Smith 1986).

In the present study, consideration was given to the nutritional benefits derived from the main crops, for example the importance of beans as a protein source (Sotelo et al. 1995). Potential nutritional benefits derived from the secondary crops were also given weight when developing cropping system treatments for comparison, particularly the protein and mineral content of faba beans and amaranth (Rani and Hira 1993, National Research Council 1984) and the vitamin content of tomatoes and husk tomato (Bock et al. 1995, Tapadia et al. 1995). As a result of the importance to farm families of increased production, efficiency of input use, and improvements in nutritional quality, an economic,

energetic, and nutritional analysis of the yields in corn and bean cropping systems was carried out. This analysis aimed to determine how adding secondary crops to corn and beans would affect the economic and nutritional benefits derived from the cropping systems tested.

### Methods and Materials

Over a period of 1 year (May 1996 - April 1997), 3 alternative corn and bean cropping systems were monitored for production costs, market prices, and yields, to determine relative benefits of the 3 systems in terms of economic return, energy, and nutrition. Treatment 1 consisted of corn monoculture followed by black bean monoculture. Treatment 2 (high-risk intercrop) was comprised of corn at the same spacing as in Treatment 1, with the additional crops black beans, faba beans and broccoli added during the growing season, followed by black beans in the same spacing as Treatment 1 but intercropped with tomato. Likewise, Treatment 3 (low-risk intercrop) consisted of corn at the same spacing, with black beans, cilantro and amaranth added during the season, followed by black beans intercropped with husk tomato. Agronomic management and timing of planting and harvesting of all crops, as well as experimental design and plot layout, are discussed in Chapters 3 and 4.

### Yields

Corn was hand harvested, solar dried, and hand shelled, after which total grain weight and the average of 3 readings of moisture content (measured with a

Dole model 400B grain moisture tester) were recorded per plot. Plot totals were adjusted for destructive samples and reported at 15% moisture equivalent. In addition to corn grain, some fresh ears were harvested at the milk stage from lodged plants removed from the plots, following local practices to avoid vertebrate damage in ears of lodged plants. Number of ears and total weight of unhusked ears were recorded per plot.

Additionally, 10 lodged plants per plot were sampled systematically with a random start, and ears on each were weighed after husking and assigned a local market value according to ear size and quality. To obtain the energy and nutritive values of the fresh corn ears harvested, it was necessary to subtract the weight of the cob. Therefore, a sample of ears was weighed with and without the cob, and the mean cob weight as a percentage of ear weight was applied to the dehusked ear weights to calculate the grain weight of ears removed with lodged plants. Yields for all other crops were recorded as total weight of marketable product per plot. During the bean cycle, beans were hand harvested twice, shelled, and solar dried. As with the corn, total weight and percent moisture were recorded for each plot. Tomato and husk tomato were both hand harvested periodically during the final month.

Finally, land productivity for the principal crops in both corn and bean cropping cycles was expressed as kg product per ha of land. Land equivalent ratio (LER) is the amount of land that would be required in monocultures to achieve the same yields obtained in 1 ha of the polyculture (Willey 1979). While commonly used in intercropping studies to determine yield advantages that

demonstrate efficiency of land use, the LER was not applied in the current study because the secondary crops were not cultivated in monoculture.

### Economic Returns

For both corn and bean cycles, prices of all crops in the local market were noted at harvest and used in conjunction with yields to calculate gross return. In the case of broccoli and cilantro, where local market prices are based on "handfuls" of product, smaller heads and shoots, respectively, were combined to calculate total economic return per plot. For each input, cost and quantity were recorded. Inputs common to all cropping systems and comprising materials already owned by small-scale farmers (machetes and hoes) were not included. Labor inputs were recorded as time spent on every activity needed to produce each crop. Total labor time for each plot was summed for the corn cycle, the bean cycle, and the total year.

Net return per plot (total return minus production costs) was calculated without accounting for labor, because of the prevalence of family labor. Calculations of net return were made for actual market prices and for both increases and decreases in product prices of 25%, since market fluctuations are common. Net return was also divided by total labor time to give return per day of labor. Since low-resource farmers in the area utilize their own labor, this gives an indication of how much they would receive for their work. Labor productivity for the principal crops was expressed as kg product (corn or beans) per day of



labor for each treatment, and capital productivity was calculated as kg product (corn or beans) per dollar input costs.

### Energy

Energy budgets of the alternative cropping systems under study were constructed using published energy values for agricultural inputs and products. Quantities of each input, including seeds, fertilizers, and labor time (classified by activity), were recorded for each plot in both experiments. Energy expended in transportation to the market to sell products or buy inputs was not included because of the widespread use of local buses and the consequent minimal fuel use per person on these short trips. Also, by-products such as corn stalks, leaves and cobs, which are utilized as animal feed, in food preparation, and as a direct energy source, respectively, were not included because of time constraints.

Input quantities were multiplied by the closest energy values found in the literature for each (Lockeretz 1980, Pandya and Pedhadiya 1993, Pimentel 1980, Stout 1990). Energy expenditure values of human labor followed those of Gajasetti (1995), where separate energy values were utilized for light, intermediate, demanding, and very demanding labor activities, ranging from 50-250 kcal/hour. This range encompasses the general energy values of human labor given by others (Wilken 1987, Norman 1978, Fluck 1992). Norman (1978) concluded that for subsistence agricultural systems, the energy input from labor should be estimated as the total energy content of all consumed foods, since the

energy in metabolized foods used as work must be enough to supply energy for all the family's activities. Fluck (1992) suggested that calculating energy content of consumed foods as labor be utilized for systems lacking fossil fuel inputs, while the method of net energy analysis, estimating the portion of energy in the gross national product that is sequestered in agricultural labor, be utilized where the predominant energy source is derived from fossil fuels that ultimately support all human activities, including agricultural labor.

The current study involves an intermediate situation, where a large part of the food consumed is produced by the same family and most of the activities and consumption of the community are not nearly as dependent on fossil fuel energy as in industrialized societies. Therefore, a typical basal metabolic rate (48 kcal/hour) was subtracted from values for gross energy expenditures, giving net metabolic energy, or the energy value of food consumed by labor (Gajaseni 1995, Fluck 1992). For each corn and bean cropping system, agricultural activities were categorized by level of work, and the corresponding energy values were applied. Very demanding work included land and seedbed preparation, weeding, mounding corn and applying chicken manure, while demanding work included planting, reseeding, transplanting, removing lodged corn plants, and turning down corn ears, and intermediate work included applying fertilizer and harvesting.

Percentage of total energy inputs derived from labor was also calculated for each treatment. All energy values of products were obtained from the USDA Nutrient Database (USDA 1997) and multiplied by yields in weight of product per

plot to give output energies. The 2 most commonly utilized measures of energy use in agro-ecosystems are the energy ratio (also referred to as efficiency ratio) and energy productivity. Energy ratio, defined as energy output from agricultural products divided by the energy contained in inputs (Fluck 1980), was calculated for each treatment from the above input and output totals in both the corn and bean cycles, as well as the entire year. Weights of yields from the principal crops (corn and beans) were used to calculate energy productivity, the quantity of product divided by total energy inputs, which measures the system's productivity from an energy point of view (Fluck 1979).

### Nutrition

Relative nutritional benefits of the cropping systems tested were evaluated by calculating nutritional yields of each treatment in both the corn-based and bean-based experiments, in terms of energy, protein, principal minerals (calcium, iron, magnesium, and phosphorus) and principal vitamins (Vitamin C, pro-Vitamin A, thiamin, riboflavin, niacin, pantothenic acid, Vitamin B<sub>6</sub>, Vitamin E and folate). Weight of each product per plot was multiplied by the corresponding nutrient values per weight, taken from data on chemical composition of food products in the USDA Nutrient Database (USDA 1997). Nutrient yields of products were summed for each plot, and total yields per plot of each nutrient were then divided by the U.S. Recommended Daily Allowance (RDA) for that nutrient (Wotecki and Thomas, eds. 1992). This gives the number of days the RDA of each nutrient is satisfied for one person by the yields

obtained from each plot, an indication of nutritional completeness provided by home consumption of the products in each treatment.

### Statistical Analysis

All evaluations of yield (weights of products, productivities, profit with and without labor, energy ratio, and days that nutrients fulfill the RDA) for the corn cycle, the bean cycle, and totals for the year (where appropriate) were subjected to an Analysis of Variance, to determine effects of cropping system (using the GLM procedure in SAS at  $\alpha=0.05$ ). The Student-Newman-Keuls test was used to separate differences in treatment means when they were detected (SAS Institute 1990). Although transformed data were used to determine treatment differences, means reported in tables are not transformed.

## Results and Discussion

The alternative cropping systems tested in this study comprise the intercrop type in which a staple food crop is the main crop and secondary crops are added. All analyses are thus based on the objective of sustaining the yield of the main crops (corn and beans) while maximizing total return and efficiency of resource use.

### Yields

Yields of the principal crops in both alternative intercrop treatments for both the corn and bean cycles were maintained at the level of the respective

monocultures (Table 6-1). Taking into account only the principal crops, land productivity was the same. Thus, land is utilized more efficiently when the secondary crops are considered (Figure 6-1). In addition, yields in all treatments were considerably higher than the mean yield of corn reported for Guatemala, which is 1131 kg/ha (CATIE 1990a).

In the corn cycle, the corn crop dominated production, with relatively low yields of secondary crops (Figure 6-2). Cilantro and amaranth had poor establishment, while poor seed quality of broccoli and diseases in black beans and faba beans contributed to low yields. On the other hand, the secondary crop husk tomato in the bean cycle yielded very well (Figure 6-3). Reductions in yield of tomato can be attributed primarily to disease.

Where the objective of an intercrop is to have complete yield of a main crop and some yield of a secondary crop, there is a yield advantage when there is any yield of the secondary crop (Willey 1979). This is the case in the current study, and as in other intercropping systems in this category, further investigation should attempt to maximize the yields of secondary crops without reducing the yields of the main crops. In addition, future studies involving production of the secondary crops concurrently in monoculture would permit a calculation of land equivalent ratio for each cropping system, thereby quantifying the advantages of the intercrops in terms of land use efficiency.



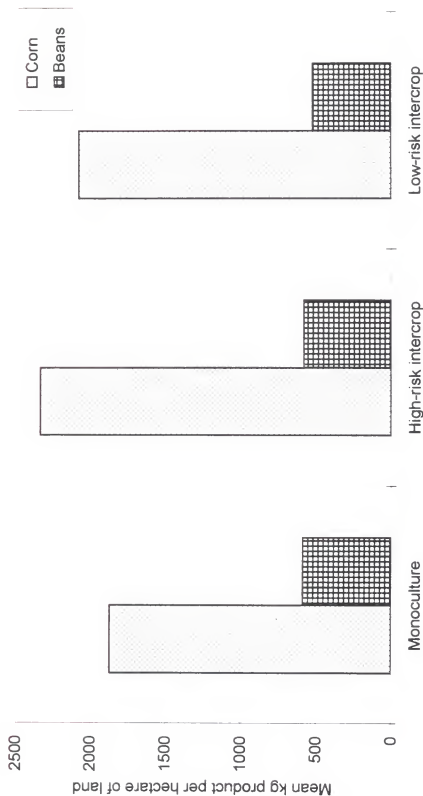


Figure 6-1. Land productivity for corn and beans in monoculture and two alternative cropping systems, May 1996-April 1997 (high-risk intercrop = corn with black beans, faba beans and broccoli, followed by black beans with tomato; low-risk intercrop = corn with black beans, cilantro and amaranth, followed by black beans with husk tomato). No significant differences were detected for either product (Student-Newman-Keuls test,  $\alpha=0.05$ ,  $n=6$ ).

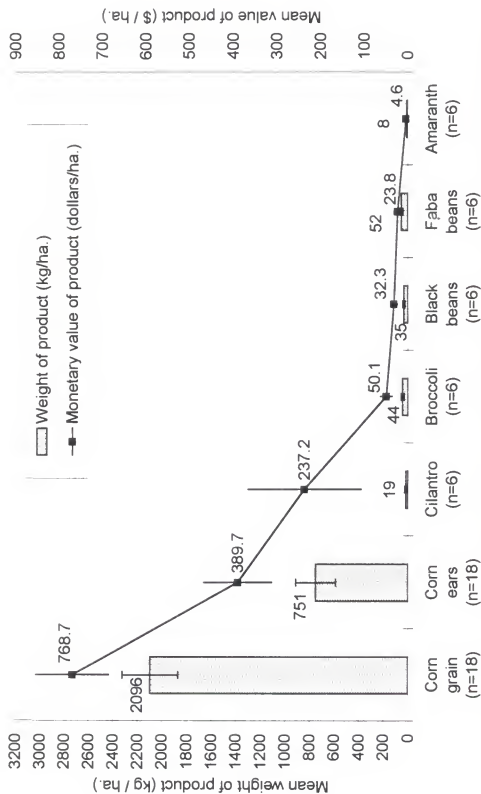


Figure 6-2. Mean yields (weight and monetary value)  $\pm$  SEM of crops in corn-based cropping systems during the rainy season of 1996.



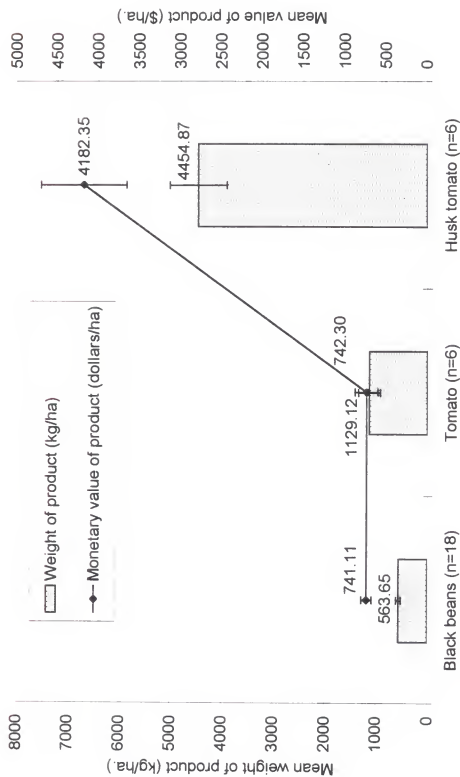


Figure 6-3. Mean yields (weight and monetary value)  $\pm$  SEM of crops in bean-based cropping systems during the dry season of 1997.

### Economic Returns

Analysis of inputs revealed that both intercropping treatments required greater amounts of labor than the respective monocultures of the main crops for both the corn and bean cycles (Table 6-2). Where labor is scarce and productivity of the main crops is the primary objective, intercropping would not utilize labor as efficiently as the monocultures (Figure 6-4). However, where family labor is available, the use of these alternatives would provide a greater opportunity to work, as long as the net return provides a wage rate acceptable to the farmer and higher than the monoculture. Many farmers in the study area accept agricultural wage labor when available and continue to produce their own crops simultaneously. That situation implies that either labor is available and paid work scarce, or that farmers value the time spent on their own crops, despite receiving lower returns on them than from paid labor. Both explanations are probably relevant to small-scale farmers in the area, given the scarcity of land and the risk involved in foregoing production of staple food crops.

To evaluate the added opportunity to work in terms of overall benefits of the intercrops, the economic return and labor rate received for each cropping system were examined. For the corn cycle, there were no differences in net economic return between the monoculture and either intercrop, for both product prices at time of harvest and for price fluctuations of 25% (Table 6-3). As a result, the labor rate received by the farmer was no higher in either intercrop (Table 6-4).

Table 6-2. Labor inputs (mean hours per plot  $\pm$  SEM) for monoculture and two alternative cropping systems, May 1996–April 1997 (high-risk intercrop = corn with black beans, faba beans and broccoli, followed by black beans with tomato; low-risk intercrop = corn with black beans, cilantro and amaranth, followed by black beans with husk tomato).

|                     | Mean hours of labor $\pm$ SEM |                    |                     |
|---------------------|-------------------------------|--------------------|---------------------|
|                     | Corn cycle                    | Bean cycle         | Total for year      |
| Monoculture         | 33.40 $\pm$ 1.45 c            | 56.61 $\pm$ 2.85 b | 90.00 $\pm$ 1.84 c  |
| High-risk intercrop | 48.05 $\pm$ 0.92 b            | 87.16 $\pm$ 2.53 a | 135.21 $\pm$ 1.84 b |
| Low-risk intercrop  | 65.22 $\pm$ 1.91 a            | 83.11 $\pm$ 2.43 a | 148.33 $\pm$ 1.89 a |

Treatment means within a cropping cycle followed by different letters are significantly different at  $\alpha=0.05$  (Student-Newman-Keuls test,  $n=6$ ).

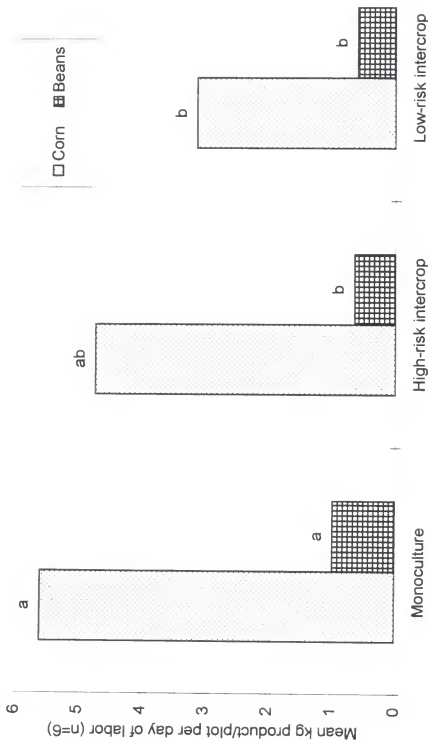


Figure 6-4. Labor productivity for corn and beans in monoculture and two alternative cropping systems, May 1996-April 1997 (high-risk intercrop = corn with black beans, faba beans and broccoli, followed by black beans with tomato; low-risk intercrop = corn with black beans, cilantro and amaranth, followed by black beans with hush tomato). Treatment means for each product with the same letter are not significantly different (Student-Newman-Keuls test,  $\alpha=0.05$ ).

Table 6-3. Total net economic return (mean dollars/day  $\pm$  SEM) for monoculture and two alternative cropping systems, May 1996 - April 1997, calculated for actual market prices during experimental year and fluctuations of 25% (high-risk intercrop = corn with black beans, faba beans and broccoli, followed by black beans with tomato; low-risk intercrop = corn with black beans, cilantro and amaranth, followed by black beans with husk tomato).

|             | Mean net economic return (dollars/day) per plot $\pm$ SEM |                                         |                           |
|-------------|-----------------------------------------------------------|-----------------------------------------|---------------------------|
|             | Product prices 25% lower                                  | Product prices during experimental year | Product prices 25% higher |
|             | Corn Cycle                                                |                                         |                           |
| Monoculture | 6.68 $\pm$ 1.90 a                                         | 10.05 $\pm$ 2.54 a                      | 13.42 $\pm$ 3.17 a        |
| High-risk   |                                                           |                                         |                           |
| Intercrop   | 7.44 $\pm$ 1.53 a                                         | 11.54 $\pm$ 2.04 a                      | 15.64 $\pm$ 2.55 a        |
| Low-risk    |                                                           |                                         |                           |
| intercrop   | 7.77 $\pm$ 2.85 a                                         | 11.94 $\pm$ 3.80 a                      | 16.11 $\pm$ 4.75 a        |
|             | Bean Cycle                                                |                                         |                           |
| Monoculture | 3.40 $\pm$ 0.97 b                                         | 5.38 $\pm$ 1.30 b                       | 7.37 $\pm$ 1.62 b         |
| High-risk   |                                                           |                                         |                           |
| intercrop   | 8.77 $\pm$ 1.71 b                                         | 13.28 $\pm$ 2.28 b                      | 17.79 $\pm$ 2.85 b        |
| Low-risk    |                                                           |                                         |                           |
| intercrop   | 39.42 $\pm$ 5.30 a                                        | 53.74 $\pm$ 7.07 a                      | 68.06 $\pm$ 8.84 a        |
|             | Total for year                                            |                                         |                           |
| Monoculture | 10.08 $\pm$ 2.56 b                                        | 15.43 $\pm$ 3.42 b                      | 20.79 $\pm$ 4.27 b        |
| High-risk   |                                                           |                                         |                           |
| intercrop   | 16.21 $\pm$ 2.00 b                                        | 24.82 $\pm$ 2.66 b                      | 33.44 $\pm$ 3.33 b        |
| Low-risk    |                                                           |                                         |                           |
| intercrop   | 47.19 $\pm$ 7.58 a                                        | 65.68 $\pm$ 10.11 a                     | 84.17 $\pm$ 12.63 a       |

Treatment means within a cropping cycle followed by different letters are significantly different at  $\alpha=0.05$  (Student-Newman-Keuls test,  $n=6$ ).

Table 6-4. Net economic return per day of labor (mean dollars per day  $\pm$  SEM) for monoculture and two alternative cropping systems, May 1996-April 1997, calculated for actual market prices and fluctuations of 25% (high-risk intercrop = corn with black beans, faba beans and broccoli, followed by black beans with tomato; low-risk intercrop = corn with black beans, cilantro and amaranth, followed by black beans with husk tomato).

|                     | Mean labor rate (dollars/day) per plot $\pm$ SEM |                                         |                           |
|---------------------|--------------------------------------------------|-----------------------------------------|---------------------------|
|                     | Product prices 25% lower                         | Product prices during experimental year | Product prices 25% higher |
| Monoculture         | 1.65 $\pm$ 0.48 a                                | Corn Cycle                              |                           |
|                     |                                                  | 2.48 $\pm$ 0.65 a                       | 3.30 $\pm$ 0.81 a         |
|                     |                                                  |                                         |                           |
| High-risk intercrop | 1.26 $\pm$ 0.28 a                                | 1.95 $\pm$ 0.38 a                       | 2.65 $\pm$ 0.48 a         |
| Low-risk intercrop  | 0.99 $\pm$ 0.38 a                                | 1.52 $\pm$ 0.51 a                       | 2.05 $\pm$ 0.64 a         |
| Monoculture         | 0.47 $\pm$ 0.13 b                                | Bean Cycle                              |                           |
|                     |                                                  | 0.75 $\pm$ 0.17 b                       | 1.03 $\pm$ 0.22 b         |
|                     |                                                  |                                         |                           |
| High-risk intercrop | 0.81 $\pm$ 0.15 b                                | 1.22 $\pm$ 0.21 b                       | 1.63 $\pm$ 0.26 b         |
| Low-risk intercrop  | 3.78 $\pm$ 0.46 a                                | 5.15 $\pm$ 0.62 a                       | 6.52 $\pm$ 0.77 a         |
| Monoculture         | 0.89 $\pm$ 0.22 b                                | Total for year                          |                           |
|                     |                                                  | 1.37 $\pm$ 0.29 b                       | 1.84 $\pm$ 0.37 b         |
|                     |                                                  |                                         |                           |
| High-risk intercrop | 0.95 $\pm$ 0.11 b                                | 1.46 $\pm$ 0.14 b                       | 1.97 $\pm$ 0.17 b         |
| Low-risk intercrop  | 2.54 $\pm$ 0.39 a                                | 3.53 $\pm$ 0.52 a                       | 4.53 $\pm$ 0.65 a         |

Treatment means within a cropping cycle followed by different letters are significantly different at  $\alpha=0.05$  (Student-Newman-Keuls test,  $n=6$ ).

However, for the bean cycle, the low-risk intercrop (beans and husk tomato) provided greater economic return and a higher labor rate, calculated both at harvest time prices and with 25% fluctuations in price (Tables 6-3 and 6-4). Mean return per day of labor in this intercrop (\$5.15) is greater than the typical agricultural wage for the area at that time (\$3.33).

Over the entire year, the return on the low-risk cropping system gave a labor rate comparable to that of the typical agricultural wage, even when considering greater labor requirements and poor secondary yields in the corn-based intercrop. For the main crops, which are staple foods, markets are less stable than yields, and therefore it would be advantageous for the farm family to produce corn and beans rather than to buy them. At the same time, they could be receiving cash plus additional nutritional benefits from the secondary crops, particularly husk tomato (Figure 6-3). To improve overall return of the low-risk cropping system, however, yields of secondary crops in corn would have to be increased. Improving the yield of cilantro is particularly promising, given this crop's relatively high return despite poor yield (Figure 6-2).

When efficiency of resources is considered, production of the main crops per unit of capital inputs was the same for all treatments in the corn cycle, but in the bean cycle it was greater in the monoculture of bean than for the intercrops (Figure 6-5). Production costs were similar for the corn and bean cycles, because the most costly input was fertilizer. However, the high production of corn in all treatments made differences in input costs less consequential than in the bean cycle, since production of beans in terms of weight was lower.

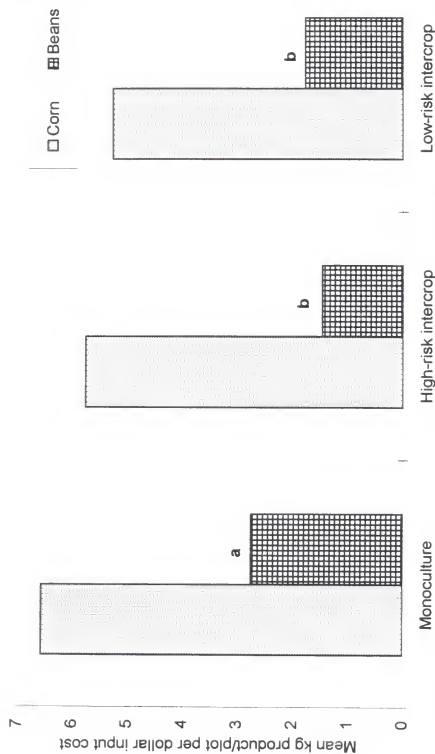


Figure 6-5. Capital productivity for corn and beans in monoculture and two alternative cropping systems, May 1996-April 1997 (high-risk intercrop = corn with black beans, faba beans and broccoli, followed by black beans with tomato; low-risk intercrop = corn with black beans, cilantro and amaranth, followed by black beans with husk tomato). Treatment means for each product with the same letter or no letters are not significantly different (Student-Newman-Keuls test,  $\alpha=0.05$ ,  $n=6$ ).



For both cycles, efficiency of capital input can be improved, particularly by more efficient use of fertilizers. The fertilization plan followed in the experiments ensured that there would be no nutrient deficiencies in the plants, so that lack of fertilization would not affect the results. Consequently, greater amounts of fertilizer were probably applied than necessary, which increased production costs unnecessarily. Therefore, net returns are conservative. Further studies are necessary to define optimum fertilizer use in these cropping systems with respect to optimization of economic return. In addition, as mentioned previously, yields of secondary crops can be improved to increase overall economic return of the intercrops.

### Energy

Energy budgets for the corn and bean cycles are given in Tables 6-5 and 6-6. The largest energy input for both the corn and bean cycles is from urea. Nitrogen fertilizer is also the greatest source of energy input for U.S. corn production and is the most energy consumptive of all fertilizers (Pimentel and Burgess 1980, Lockeretz 1980). While the tomato crop is a high energy consumer in industrialized agriculture because of intense fuel and pesticide use (Fluck et al. 1992), in the current experiments, the bean and tomato treatment did not require considerably greater amounts of energy inputs. However, use of fossil fuel-based fertilizers can be reduced in all the cropping systems tested, by optimizing both quantity and placement. Further studies are needed to

Table 6-5. Energy budgets for corn-based cropping systems, 1996 rainy season (high-risk intercrop = corn with black beans, faba beans and broccoli; low-risk intercrop = corn with black beans, cilantro and amaranth).

|                      |                     | Energy inputs and outputs (MJ/plot) |                     |                    |
|----------------------|---------------------|-------------------------------------|---------------------|--------------------|
|                      |                     | Monoculture                         | High-risk intercrop | Low-risk intercrop |
| Input                | Corn seed           | 5.624                               | 5.624               | 5.624              |
|                      | Bean seed           |                                     | 2.659               | 2.659              |
|                      | Broccoli seed       |                                     | 0.003               |                    |
|                      | Faba bean seed      |                                     | 0.525               |                    |
|                      | Cilantro seed       |                                     |                     | 0.230              |
|                      | Amaranth seed       |                                     |                     | 0.008              |
|                      | Fertilizers:        |                                     |                     |                    |
|                      | 15-15-15            |                                     | 0.773               |                    |
|                      | Urea                | 99.096                              | 148.699             | 148.699            |
|                      | DAP                 | 24.280                              | 36.501              | 36.501             |
|                      | Muriate of potash   | 3.310                               | 4.976               | 4.976              |
|                      | Chicken manure      | 24.359                              | 24.359              | 24.359             |
|                      | Labor               | 22.702                              | 30.513              | 36.278             |
|                      | Total energy inputs | 179.371                             | 254.632             | 259.334            |
| Output               | Corn                | 476.494                             | 530.70              | 461.836            |
|                      | Beans               |                                     | 4.147               | 7.922              |
|                      | Broccoli            |                                     | 149.370             |                    |
|                      | Faba beans          |                                     | 3.303               |                    |
|                      | Cilantro            |                                     |                     | 0.193              |
|                      | Amaranth            |                                     |                     | 1.448              |
| Total energy outputs |                     | 476.494                             | 687.520             | 471.399            |

Energy values utilized are as follows: corn: 15.270 MJ/kg; beans: 14.270 MJ/kg; broccoli: 1.170 MJ/kg; faba beans: 14.270 MJ/kg; cilantro seed: 12.450 MJ/kg; cilantro leaves: 0.840 MJ/kg; amaranth seed: 15.650 MJ/kg; 15-15-15: 12.450 MJ/kg; urea: 27.542 MJ/kg; diammonium phosphate (DAP): 20.267 MJ/kg; muriate of potash: 2.763 MJ/kg; chicken manure: 2.471 MJ/kg; and human labor: 0.867-3.367 kcal/min (Gajaseneni 1995; Lockeretz 1980; Pandya and Pedhadiya 1993; Pimentel 1980; Stout 1990).

Table 6-6. Energy budgets for bean-based cropping systems, 1997 dry season (high-risk intercrop = black beans with tomato; low-risk intercrop = black beans with husk tomato).

|                      |                   | Energy inputs and outputs (MJ/plot) |                     |                    |
|----------------------|-------------------|-------------------------------------|---------------------|--------------------|
|                      |                   | Monoculture                         | High-risk intercrop | Low-risk intercrop |
| Input                |                   |                                     |                     |                    |
|                      | Bean seed         | 7.724                               | 7.724               | 7.724              |
|                      | Tomato seed       |                                     | 0.004               |                    |
|                      | Husk tomato seed  |                                     |                     | 0.006              |
|                      | Fertilizers:      |                                     |                     |                    |
|                      | 15-15-15          |                                     | 1.546               | 1.546              |
|                      | Urea              | 65.991                              | 99.206              | 99.206             |
|                      | DAP               | 24.280                              | 36.501              | 36.501             |
|                      | Muriate of potash | 3.310                               | 4.976               | 4.976              |
|                      | Captan            | 0.238                               | 0.238               | 0.238              |
|                      | Labor             | 41.745                              | 53.820              | 49.982             |
| Total energy inputs  |                   | 143.288                             | 204.016             | 200.181            |
| Output               |                   |                                     |                     |                    |
|                      | Beans             | 100.672                             | 99.720              | 89.486             |
|                      | Tomato            |                                     | 12.186              |                    |
|                      | Husk tomato       |                                     |                     | 73.245             |
| Total energy outputs |                   | 100.672                             | 111.906             | 162.731            |

Energy values utilized are as follows: beans: 14.270 MJ/kg; tomato: 0.88 MJ/kg; husk tomato: 1.34 MJ/kg; 15-15-15: 12.450 MJ/kg; urea: 27.542 MJ/kg; diammonium phosphate (DAP): 20.267 MJ/kg; muriate of potash: 2.763 MJ/kg; Captan: 114.600 MJ/kg; and human labor: 0.867-3.367 kcal/min (Gajaseni 1995; Lockeretz 1980; Pandya and Pedhadiya 1993; Pimentel 1980; Stout 1990).

determine to what extent such reductions can be made without greatly affecting yields or economic returns.

The percentage of total energy inputs derived from labor was between 11 and 32.5%. During the corn cycle, this percentage was greater for the intercrops than for the monoculture and greater for the low-risk than the high-risk intercrop (Figure 6-6). The increase in labor energy input from the monoculture to the high-risk intercrop and further to the low-risk intercrop was greater than the increase in energy from fertilizer use. The opposite occurred in the bean cycle, where the monoculture had the highest percent of energy inputs derived from labor and the low-risk intercrop had the lowest percent of labor energy inputs. Labor energy inputs for all treatments in the bean cycle were higher than in the corn cycle because of labor expended in irrigation during the bean cycle.

In terms of energy productivity, quantity of principal product (corn or beans) per energy input was the same for all treatments for both the corn and bean cycles (Figure 6-7). When energy inputs are compared to energy output in each cropping system, both the corn and bean cycles again showed no difference in energy ratios among treatments (Table 6-7). Energy ratios for comparably managed subsistence corn production systems are variable, from 3.11 and 13.6 in Guatemala (Pimentel and Pimentel 1979, Leach 1976) to 128.3 in Mexico (Pimentel and Burgess 1980).

It is useful to examine the efficiency of cropping systems both in terms of energy inputs from human labor and energy inputs derived from fossil fuels. Efficiency of labor energy inputs can indicate which system has higher net

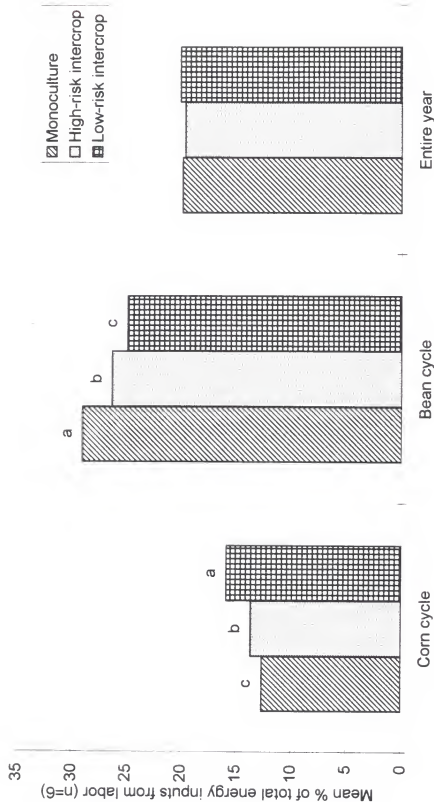


Figure 6-6. Percent of total energy inputs derived from labor for corn and bean in monoculture and two alternative cropping systems, May 1996-April 1997 (high-risk intercrop = corn with black beans, faba beans and broccoli, followed by black beans with tomato; low-risk intercrop = corn with black beans, cilantro and amaranth, followed by black beans with hush tomato). Treatment means with the same letter or no letters are not significantly different (Student-Newman-Keuls test,  $\alpha=0.05$ ).

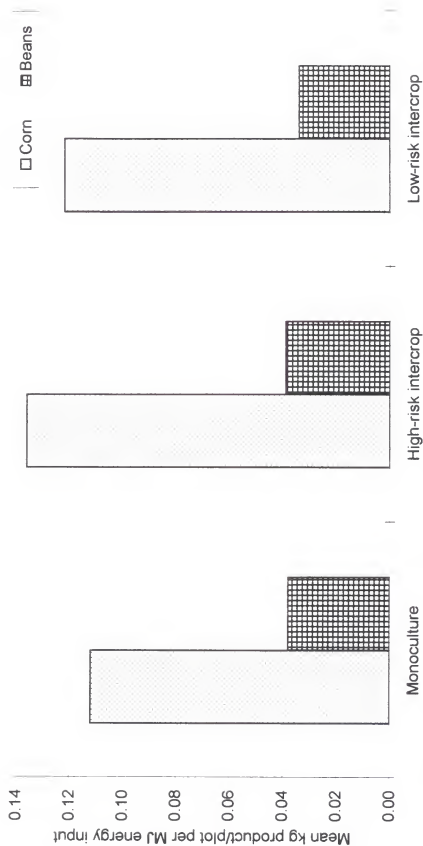


Figure 6-7. Energy productivity for corn and beans in monoculture and two alternative cropping systems, May 1996-April 1997 (high-risk intercrop = corn with black beans, faba beans and broccoli, followed by black beans with tomato; low-risk intercrop = corn with black beans, cilantro and amaranth, followed by black beans with husk tomato). No significant differences were detected for either product (Student-Newman-Keuls test,  $\alpha=0.05$ ,  $n=6$ ).

Table 6-7. Energy efficiency ratios (mean output energy/input energy  $\pm$  SEM) for monoculture and two alternative cropping systems, May 1996-April 1997 (high-risk intercrop = corn with black beans, faba beans and broccoli, followed by black beans with tomato; low-risk intercrop = corn with black beans, cilantro and amaranth, followed by black beans with husk tomato).

|                                   | Mean energy ratio $\pm$ SEM |                 |                 |
|-----------------------------------|-----------------------------|-----------------|-----------------|
|                                   | Corn cycle                  | Bean cycle      | Total for year  |
| Energy output/total energy inputs |                             |                 |                 |
| Monoculture                       | 2.66 $\pm$ 0.48             | 0.79 $\pm$ 0.10 | 1.82 $\pm$ 0.28 |
| High-risk intercrop               | 2.12 $\pm$ 0.29             | 0.69 $\pm$ 0.09 | 1.48 $\pm$ 0.14 |
| Low-risk intercrop                | 1.82 $\pm$ 1.04             | 0.62 $\pm$ 0.14 | 1.29 $\pm$ 0.19 |
| Energy output/labor energy inputs |                             |                 |                 |
| Monoculture                       | 21.54 $\pm$ 4.29            | 2.74 $\pm$ 0.35 | 9.11 $\pm$ 1.34 |
| High-risk intercrop               | 17.94 $\pm$ 2.80            | 2.65 $\pm$ 0.39 | 8.01 $\pm$ 0.67 |
| Low-risk intercrop                | 13.33 $\pm$ 3.15            | 2.49 $\pm$ 0.58 | 6.90 $\pm$ 1.01 |

No significant differences among treatment means were detected for any of the crop cycles at  $\alpha=0.05$  (Student-Newman-Keuls test,  $n=6$ ).

energy gained from the production of crops that can be used to perform other activities. On the other hand, inclusion of fossil fuel inputs gives an indication of which cropping system uses fossil fuel inputs more efficiently, an issue that will continue to gain in importance.

For the corn cycle, energy outputs are slightly greater than total energy inputs, but are considerably higher when only labor energy inputs are considered. The energy ratios of total inputs in the bean-based cropping systems suggest energetic inefficiency (energy ratio  $< 1$ ). Tomato and husk tomato are not energetically rich crops, and the bean harvest does not produce a large quantity of product, so output is lower than input. When efficiency of labor energy use is considered, however, energy output becomes greater than input, but there is still no difference between treatments (Table 6-7).

In industrialized corn production, energy ratios are low because of high fossil fuel inputs. The ratio of corn energy output to fossil energy input has been estimated at 2.47 (Pimentel and Burgess 1980). In the present study, indirect fossil fuel inputs in the form of fertilizers contributed significantly to total energy inputs for both corn- and bean-based cropping systems. As was true for economic return, the cropping systems probably have more energy input than is necessary, due to an abundance of synthetic fertilizer, causing the energy ratios to be low.

Further studies of fertility management in these cropping systems are necessary to improve efficiency of fossil fuel-based energy use. Additionally, use of energy inputs from human labor can be made more efficient, particularly



in the low-risk corn-based intercrop (corn with black beans, cilantro and amaranth). Germination problems led to labor-intensive planting of amaranth and cilantro that might have been alleviated by planting at a lower depth. Agronomic study of optimum hand planting techniques is needed to further improve energy efficiency.

### Nutrition

When energy was evaluated in terms of total caloric yield regardless of agronomic inputs utilized, the low-risk cropping system in the bean cycle provided more energy than the other treatments (Table 6-8). In fact, for several nutritional components, either one or both of the alternative cropping systems produced significantly greater quantities than the monoculture, mostly in the bean cycle. While the only difference seen in the corn cycle was for Vitamin C (corn has negligible amounts of this nutrient), 10 out of 14 nutrients were higher in the low-risk bean intercrop (beans with husk tomato) than the monoculture. Three of these were also higher in the high-risk treatment (beans with tomato) than in the monoculture.

The most striking difference in nutrient yields was found for pro-Vitamin A (carotene), which although showing no difference among treatments for the corn cycle, was available in much greater quantity in both bean intercrops. The provision of pro-Vitamin A gives the intercrops an important advantage over the monoculture, because 11% of rural Guatemalan children suffer from Vitamin A deficiency (Menchu 1992). Protein and iron are other key nutrients often

Table 6-8. Number of days the Recommended Daily Allowance (RDA) of selected nutrients is satisfied by yields (mean  $\pm$  SEM) per plot of monoculture (corn followed by bean) and two alternative cropping systems (high-risk intercrop = corn with black beans, faba beans and broccoli followed by black beans with tomato; low-risk intercrop = corn with black beans, cilantro and amaranth followed by black beans with husk tomato) during 1996-1997.

|                     | Energy |   |       | Protein |       |   | Calcium |   |       | Iron |      |   |       |   |       |   |
|---------------------|--------|---|-------|---------|-------|---|---------|---|-------|------|------|---|-------|---|-------|---|
|                     |        |   |       |         |       |   |         |   |       |      |      |   |       |   |       |   |
| Corn cycle          |        |   |       |         |       |   |         |   |       |      |      |   |       |   |       |   |
| Monoculture         | 56.90  | ± | 10.21 | a       | 45.18 | ± | 8.11    | a | 2.18  | ±    | 0.39 | a | 46.94 | ± | 8.42  | a |
| High-risk intercrop | 64.33  | ± | 8.53  | a       | 52.46 | ± | 6.92    | a | 3.28  | ±    | 0.43 | a | 54.21 | ± | 7.16  | a |
| Low-risk intercrop  | 56.29  | ± | 12.45 | a       | 45.92 | ± | 10.12   | a | 3.17  | ±    | 0.66 | a | 47.68 | ± | 10.46 | a |
| Bean cycle          |        |   |       |         |       |   |         |   |       |      |      |   |       |   |       |   |
| Monoculture         | 12.02  | ± | 1.97  | b       | 23.43 | ± | 3.84    | a | 8.67  | ±    | 1.42 | a | 19.66 | ± | 3.23  | b |
| High-risk intercrop | 13.36  | ± | 1.62  | b       | 25.02 | ± | 3.10    | a | 9.28  | ±    | 1.15 | a | 22.94 | ± | 2.71  | b |
| Low-risk intercrop  | 19.43  | ± | 2.59  | a       | 28.90 | ± | 4.13    | a | 11.53 | ±    | 1.61 | a | 36.30 | ± | 4.73  | a |
| Total for year      |        |   |       |         |       |   |         |   |       |      |      |   |       |   |       |   |
| Monoculture         | 68.91  | ± | 11.73 | a       | 68.61 | ± | 11.23   | a | 10.85 | ±    | 1.73 | a | 66.60 | ± | 11.01 | a |
| High-risk intercrop | 77.69  | ± | 7.92  | a       | 77.48 | ± | 6.07    | a | 12.56 | ±    | 1.06 | a | 77.14 | ± | 6.46  | a |
| Low-risk intercrop  | 75.72  | ± | 14.25 | a       | 74.82 | ± | 12.81   | a | 14.70 | ±    | 2.00 | a | 83.98 | ± | 14.10 | a |

Treatment means for each nutrient followed by the same letter are not significantly different at  $\alpha=0.05$  (Student-Newman-Keuls test,  $n=6$ ).

Table 6-8—Continued.

|                     | Magnesium      |         | Phosphorus |         | Vitamin C  |         | Thiamin  |         |
|---------------------|----------------|---------|------------|---------|------------|---------|----------|---------|
|                     |                |         |            |         | Corn cycle |         |          |         |
| Monoculture         | 46.94 ±        | 8.42 a  | 65.47 ±    | 11.75 a | 0.00 ±     | 0.00 b  | 80.02 ±  | 14.36 a |
| High-risk intercrop | 54.21 ±        | 7.16 a  | 75.26 ±    | 9.95 a  | 8.34 ±     | 2.64 a  | 91.94 ±  | 12.22 a |
| Low-risk intercrop  | 47.68 ±        | 10.46 a | 65.91 ±    | 14.50 a | 0.47 ±     | 0.20 b  | 81.05 ±  | 17.95 a |
|                     | Bean cycle     |         |            |         |            |         |          |         |
| Monoculture         | 30.14 ±        | 4.94 b  | 24.82 ±    | 4.07 b  | 0.00 ±     | 0.00 c  | 42.30 ±  | 6.94 a  |
| High-risk intercrop | 33.66 ±        | 4.06 b  | 27.91 ±    | 3.36 b  | 44.11 ±    | 8.26 b  | 47.35 ±  | 5.71 a  |
| Low-risk intercrop  | 54.12 ±        | 7.08 a  | 43.38 ±    | 5.70 a  | 106.58 ±   | 13.31 a | 53.63 ±  | 7.60 a  |
|                     | Total for year |         |            |         |            |         |          |         |
| Monoculture         | 129.12 ±       | 21.65 a | 90.28 ±    | 14.99 a | 0.00 ±     | 0.00 c  | 122.32 ± | 20.01 a |
| High-risk intercrop | 146.59 ±       | 13.58 a | 103.17 ±   | 8.94 a  | 52.45 ±    | 7.24 b  | 139.30 ± | 10.94 a |
| Low-risk intercrop  | 153.19 ±       | 27.08 a | 109.28 ±   | 18.77 a | 107.05 ±   | 13.35 a | 134.68 ± | 23.02 a |

Treatment means for each nutrient followed by the same letter are not significantly different at  $\alpha=0.05$  (Student-Newman-Keuls test,  $n=6$ ).

Table 6-8—Continued.

|                     | Riboflavin |        | Niacin   |         | Pantothenic acid |        | Vitamin B6       |
|---------------------|------------|--------|----------|---------|------------------|--------|------------------|
|                     |            |        |          |         | Corn cycle       |        |                  |
| Monoculture         | 36.86 ±    | 6.62 a | 56.54 ±  | 10.15 a | 13.22 ±          | 2.37 a | 96.95 ± 17.40 a  |
| High-risk intercrop | 42.21 ±    | 5.57 a | 63.75 ±  | 8.45 a  | 15.49 ±          | 2.05 a | 109.25 ± 14.48 a |
| Low-risk intercrop  | 36.63 ±    | 8.11 a | 55.48 ±  | 12.32 a | 13.45 ±          | 2.95 a | 94.99 ± 21.09 a  |
|                     |            |        |          |         | Bean cycle       |        |                  |
| Monoculture         | 8.00 ±     | 1.31 b | 6.89 ±   | 1.13 b  | 6.34 ±           | 1.04 b | 10.08 ± 1.65 c   |
| High-risk intercrop | 11.84 ±    | 1.34 b | 11.18 ±  | 1.28 b  | 9.70 ±           | 1.10 b | 15.53 ± 1.77 b   |
| Low-risk intercrop  | 18.37 ±    | 2.33 a | 56.69 ±  | 7.00 a  | 13.83 ±          | 1.76 a | 24.27 ± 3.07 a   |
|                     |            |        |          |         | Total for year   |        |                  |
| Monoculture         | 44.87 ±    | 7.63 a | 63.43 ±  | 11.00 a | 19.56 ±          | 3.21 a | 107.04 ± 18.65 a |
| High-risk intercrop | 54.05 ±    | 5.36 a | 74.92 ±  | 8.26 a  | 25.20 ±          | 2.07 a | 124.78 ± 14.15 a |
| Low-risk intercrop  | 55.00 ±    | 9.95 a | 112.17 ± | 18.79 a | 27.28 ±          | 4.40 a | 119.25 ± 23.48 a |

Treatment means for each nutrient followed by the same letter are not significantly different at  $\alpha=0.05$  (Student-Newman-Keuls test,  $n=6$ ).

Table 6-8—Continued.

|                     | Folate   |         | pro-Vitamin A |         | Vitamin E |        |
|---------------------|----------|---------|---------------|---------|-----------|--------|
|                     |          |         | Corn cycle    |         |           |        |
| Monoculture         | 14.81 ±  | 2.66 a  | 29.24 ±       | 5.25 a  | 11.63 ±   | 2.09 a |
| High-risk intercrop | 23.11 ±  | 3.00 a  | 34.25 ±       | 4.55 a  | 13.44 ±   | 1.78 a |
| Low-risk intercrop  | 20.69 ±  | 4.61 a  | 29.63 ±       | 6.64 a  | 11.67 ±   | 2.59 a |
| Bean cycle          |          |         |               |         |           |        |
| Monoculture         | 78.31 ±  | 12.85 a | 0.24 ±        | 0.04 b  | 0.74 ±    | 0.12 b |
| High-risk intercrop | 82.76 ±  | 10.33 a | 17.50 ±       | 3.24 a  | 0.73 ±    | 0.10 b |
| Low-risk intercrop  | 79.17 ±  | 12.21 a | 12.68 ±       | 1.58 a  | 11.03 ±   | 1.37 a |
| Total for year      |          |         |               |         |           |        |
| Monoculture         | 93.12 ±  | 14.90 a | 29.48 ±       | 5.23 b  | 12.37 ±   | 2.18 b |
| High-risk intercrop | 105.88 ± | 9.44 a  | 51.75 ±       | 5.97 a  | 14.17 ±   | 1.74 b |
| Low-risk intercrop  | 99.86 ±  | 14.75 a | 42.31 ±       | 8.08 ab | 22.70 ±   | 3.86 a |

Treatment means for each nutrient followed by the same letter are not significantly different at  $\alpha=0.05$  (Student-Newman-Keuls test,  $n=6$ ).

deficient in rural areas of the country, and while there were no differences among treatments in the corn cycle, the beans and husk tomato intercrop provided significantly greater amounts of iron than either the beans and tomato intercrop or beans alone. It should be noted that RDA values are based on recommendations for healthy individuals in the U.S. and are not considered appropriate guidelines for individuals with nutrient deficiencies (Standing Committee on the Scientific Evaluation of Dietary Reference Intakes 1997). Therefore, in the present analysis, the number of days the RDA is satisfied is not a strict measure of satisfactory dietary composition, but rather the values are meant for comparison of general nutritional benefits among alternative cropping systems.

Cropping systems that provide nutritional diversity are advantageous to small-scale farmers with elements of both subsistence and commercial agriculture. The impacts of agricultural change on the nutritional status of such farming communities has been evaluated considerably. A shift to commercial production often causes a deterioration in nutritional status for the poorest families, partly as a result of reduced crop diversity. In these cases, families maintaining the greatest degree of food self-sufficiency tend to be better off from a nutritional perspective (Dewey 1981). The intercrops studied here can provide a greater degree of protection against the hazards of a shift to cash crops, and in particular the low-risk intercrop is the most advantageous in terms of nutritional yields.

### Conclusions

For small-scale farm families in the process of commercialization, economic return may be the primary objective; however, their overall well-being can be jeopardized by narrowly based recommendations that ignore other goals such as dietary diversity and food security. The corn- and bean-based intercrops tested were designed to meet all of these goals. To do so, an alternative cropping system must not only be capable of maintaining the level of yield of the respective corn or bean monoculture, but must also provide greater economic and nutritional return without incurring greater energy costs.

For the alternative intercrops tested, the yields of the principal crops were not changed by the addition of secondary crops to corn or beans, for either the high-risk or the low-risk intercrop treatments. Furthermore, the low-risk intercrop in the bean cycle (beans with husk tomato) provided greater economic return and nutritional benefit than the bean monoculture, and these advantages persisted when that cropping system was analyzed on a per year basis (including the corn cycle). Additionally, the low-risk intercrop, with higher labor requirements, provided greater opportunity for labor productivity. In fact, for neither intercrop alternative was the net economic return per day of labor lower than in the monoculture. The advantages of the intercrop systems were not at the expense of energy costs, since the energy efficiency was the same for all treatments.

There exists a need to improve economic returns and energy efficiency of the intercrops by increasing yields of secondary crops, particularly in the corn

cycle, and optimizing the dollar return from fertilizers. Additionally, yields in the high-risk intercrop could be improved in both the corn and bean cycles by control of disease. However, given the problematic nature of chemical control and the difficulty in implementing Integrated Pest Management programs for small-scale tropical farmers, combined with a lack of exceptional potential economic returns from the crops involved, the wisdom of pursuing this line of research is questionable.

The economic, energetic and nutritional analyses presented here suggest instead that improvements be made in yields and subsequent returns from the low-risk intercrop alternative. The research demonstrates that it is possible to start with the accepted production methods of the key staple food crops of a community, in this case corn and beans, and add to the system potentially beneficial crops that increase net economic return without risking food security or dietary diversity. Therefore, while further studies are needed to improve the low-risk alternative intercrop suggested here (corn intercropped with black beans, cilantro and amaranth followed by black beans intercropped with husk tomato), many other possibilities exist, and both researchers and small-scale farmers can explore their potential benefits.



## CHAPTER 7 SUMMARY AND CONCLUSIONS

Rising population and limited land available for agricultural production, coupled with the inability of the staple food crops, corn and beans, to satisfy the needs of highland Guatemalan families, has resulted in the need for more intensive production. Pressures have heightened to shift production to nontraditional export crops, which in themselves bring about ecological and economic instability for the small-scale farmer (Morales 1993, Rosset 1991). Therefore, the study presented here was designed to test the feasibility of selected intercrop systems that start with the essential food crops as the base and incorporate additional crops with potential benefits to the farm family.

### Relative Value of Alternative Corn- and Bean-Based Cropping Systems in Minimizing Pest Problems

An evaluation of insect, disease, and nematode pests, as well as damage to the main crops, revealed no evidence that the addition of the secondary crops tested would contribute to greater pest problems on either corn or beans. In fact, seasonal density of the fall armyworm (*S. frugiperda*), a key corn pest in Central America, was higher on corn in monoculture than in the high-risk intercrop (corn with black beans, faba beans and broccoli), and percentage of plants with insect damage was greater in the corn monoculture than either the high-risk intercrop or

the low-risk intercrop (corn with black beans, cilantro and amaranth). In both the corn and bean cycles, the bean being tested in monoculture and intercropped with tomato (high-risk) and husk tomato (low-risk), the intercrops tested did not increase pest problems on the staple crops and may even contribute to lower pest damage.

The importance of natural pest control cannot be overemphasized for small-scale resource-poor farmers with limited access to information. Here, the intercrops did not reduce the population densities of beneficial insects on the main crops, making them compatible with strategies to conserve natural enemies. We cannot easily determine under what circumstances intercropping reduces pest populations and under what conditions the natural enemies hypothesis of Root (1973) is more important than the resource concentration hypothesis, because of the multitude of factors involved. Therefore, we cannot make intercropping recommendations that are relevant in all places and at all times. However, the effects of chemical pesticides on natural enemies have been documented across cropping systems, geographic areas, and other conditions, so we can say with greater confidence that reducing pesticide sprays can increase the natural control of pests. For the most practical short-term solutions to small-scale farmers' needs, we should seek crop combinations that, in addition to providing greater economic returns and meeting other farmer objectives, do not require pesticide sprays, thereby permitting greater natural control. Of the alternatives tested, the low-risk intercrop was the most appropriate in terms of conservation of natural enemies.

The trend toward commercialized, monocultural agriculture utilizing introduced crops displaces and ignores crop choices and management techniques that are based on natural crop protection strategies. The survey of small-scale farmers in the study area revealed their greatest constraints to be access to inputs and understanding of pest management. Although these farmers are often quick to adopt new crops, they continue to utilize traditional knowledge of agricultural methods, incorporating new crops into that domain. For example, some farmers produce newly introduced vegetables on traditionally constructed and irrigated terraces. Traditional Mayan agriculture has developed strategies to effectively manage soil, water, climate and space (Wilken 1987). In both the past and present, Mayan farmers have utilized resource management strategies involving vegetational diversity in socially and environmentally compatible ways (see, for example, Barrera et al. 1977, Vargas Rivero 1983, Brush 1981).

However, the realm of traditional knowledge includes limited information on pest management, since pests have not historically been a problem. Moreover, small-scale farmers in the highlands of Guatemala have an inadequate information support system with respect to pest management. Extension services are minimal, insect identification services are non-existent in rural areas, and although an increasing number of non-governmental organizations have begun promoting organic agriculture in rural communities, much of the information farmers receive from nontraditional sources is based on recommendations for chemical pesticide applications.

Given such strong constraints as mentioned above, instead of promoting cropping systems that to be sustainable would require teaching farmers the concepts and tactics of ecological pest management, a more practical approach would be to promote the choice of crops with appreciable economic return that have inherently limited pest problems when incorporated into the traditional agricultural systems of the area. While teaching the complex concepts of pest management to farmers with limited access to information can be an overwhelming task (Barfield and Swisher 1994), small-scale farmers can more easily understand the merits of diversifying production to avoid risks and choosing crops not likely to be economically damaged by pests. The study described here evaluated only two alternative cropping systems, but by demonstrating that at least one intercropping system provided economic and nutritional advantages to the farmer, it opened the possibilities for farmer experimentation and refinement of a whole range of possible alternatives to find crop combinations that provide such advantages without requiring complex pest management decisions. Developing in farmers a confidence in their own abilities to experiment to find appropriate crop choices is immensely simpler than teaching them the concepts and mechanics of pest management, and therefore is more likely to be successful.

Relative Value of Alternative Corn- and Bean-Based Cropping Systems in  
Providing Economic and Nutritional Benefits to the Farmer

Corn and beans are an essential component of traditional Mayan agriculture, and their production systems comprise a logical place to incorporate additional

crops, particularly given the religious and economic role of corn in indigenous cultures of the Guatemalan highlands (Rojas Lima 1988). While the maintenance of these traditional crops provides for cultural needs in all the cropping systems tested, the intercrop alternatives were hypothesized to provide greater net economic and nutritional return than the monocultures. The high-risk intercrop tested the incorporation of regional and export-market oriented crops with high potential for economic return under appropriate conditions, while the low-risk intercrop involved traditional and local-market oriented crops, which were considered to provide lower but more stable returns. Both alternatives and monocultures were tested without pest management, to examine the response of each system in the absence of the farmers' pest management options.

Yields of secondary crops were low in both alternative intercrop systems involving corn, but reasons for low yields differed by cropping system. Secondary crops in the high-risk intercrop (corn with black beans, faba beans and broccoli) experienced severe pest damage that limited yields, while in the low-risk intercrop (corn with black beans, cilantro and amaranth), agronomic problems relating to germination considerably reduced plant stand. Hence, economic returns were not improved over the monoculture. However, two points are important to consider in reviewing the relative success of these intercrops. First, the yield of corn, the main crop, was not reduced by the addition of secondary crops in either alternative, which means that there was still a yield advantage, as defined by Willey (1979). Any increase in yields due to improvements in agronomic practices would further increase the yield advantage and eventually provide significantly greater economic

return, since most of the increase in production costs for the secondary crops was from greater labor requirements. Secondly, improving yields is more easily accomplished in the low-risk alternative by slightly modifying planting practices than it would be to increase yields in the high-risk alternative by adding hazardous pest control tactics or knowledge-intensive pest management tactics. While both intercrop alternatives have economic potential, the low-risk intercrop is more appropriate to the limitations of small-scale farmers in the area.

The potential benefits of intercropping with traditional crops was more clearly seen during the bean cycle of the experiment, in which the low-risk intercrop (beans with husk tomato) provided significantly greater economic and nutritional returns than the bean monoculture. These differences were so great that the advantages persisted when the cropping systems were analyzed over the entire year, including the corn cycle. Consequently, with a limited area of land, greater economic and nutritional returns per year can be accomplished by intercropping certain secondary crops with the staple dietary crops, corn and beans.

#### Concluding Remarks

From the farmers' perspective, the benefits derived from adding crops to corn and beans are not related to pests but to economic return and nutrition. By assuring that the addition of certain crops to corn and beans does not worsen pest problems, we can then concentrate on the direct benefits to the farmer. The next step involves refinements of the cropping system found to be most appropriate, the low-risk intercrop, to further increase yields of secondary crops,

particularly in corn. Farmers, as well as governmental and non-governmental organizations involved in local agricultural development, can be encouraged to continually experiment to discover other secondary crops that, when added to corn and beans, provide positive outcomes.

From a societal perspective, benefits derived from such intercrops are broader in scope. Advantages of the selected cropping systems were tested in terms of economics, nutrition, energy and pest management, but there may be additional advantages not examined here. These may include agroecological benefits, such as positive effects on soil structure and fertility, or water management, as well as socio-economic or cultural benefits, such as long-term risk aversion, all of which may also serve the individual farmer.

Additional benefits to the larger society may also be significant. For example, the conservation of plant and animal biodiversity is important for maintaining a genetically stable food base (FAO 1993, Oldfield and Alcorn 1987, Altieri 1991a). Furthermore, the environmental contamination of soil and water, as well as public health concerns resulting from chemical pesticide use, could be reduced (Pimentel et al. 1991). Finally, there may be an economic impact on the region if alternative production systems increase incomes of rural farmers who are potential consumers of goods and services.

Different cropping systems may have differential impacts on the environmental and economic situation of both the individual farmer and the larger society. A complete analysis of the sustainability of each system would involve the complete array of ecological and socio-economic components such as those

mentioned above. However, the results of this study are sufficient to immediately recommend the promotion of the low-risk intercrop tested, particularly the combination of beans with husk tomato. More importantly, long-term development of alternative cropping systems can be improved by testing traditional crops with minimal pest problems in intercropping systems involving staple food crops.

Traditional agricultural practices are better able to maintain the ecological and social integrity of the community, avoiding costly and harmful agricultural chemicals and fostering improved nutrition through yield diversity. It has therefore been proposed that agricultural development projects should attempt to increase productivity of traditional agricultural systems rather than substituting technologies inappropriate for resource-poor farmers (Altieri and Anderson 1986, Gliessman et al. 1981). The experiments involved in the study detailed here have tested crop combinations intermediary between traditional and export agricultural systems in the western Guatemalan highlands. The results of the study demonstrate the feasibility of appropriately combining crops in that region to provide for the needs of small-scale farmers to increase productivity, profits, and dietary security while maintaining traditional practices, at the same time accounting for the limitations of traditional pest management knowledge by choosing crop combinations with minimal pest problems.



APPENDIX A  
DESCRIPTIONS OF SEASONAL TRENDS IN INSECT AND BENEFICIAL  
POPULATION DENSITIES, DISEASE AND DAMAGE ON CORN IN  
MONOCULTURE AND ALTERNATIVE INTERCROPS

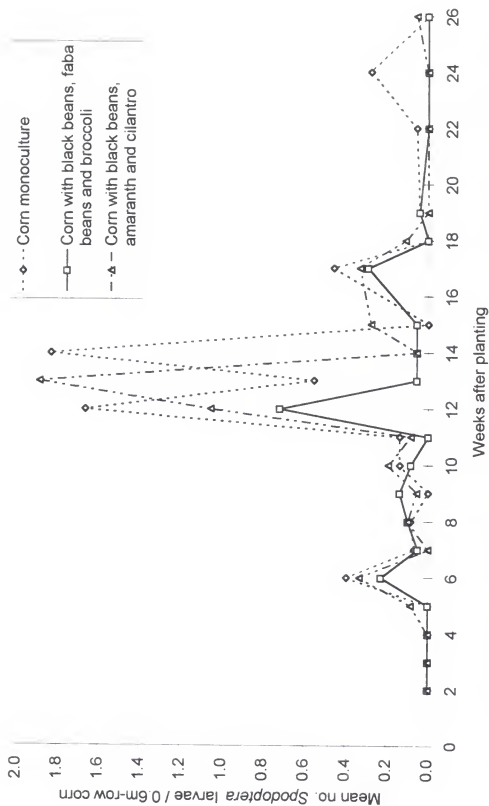


Figure A-1. Mean densities of *Spodoptera frugiperda* larvae from corn in monoculture, corn intercropped with black beans, faba beans and broccoli, and corn intercropped with black beans, amaranth and cilantro, during the rainy season of 1996.

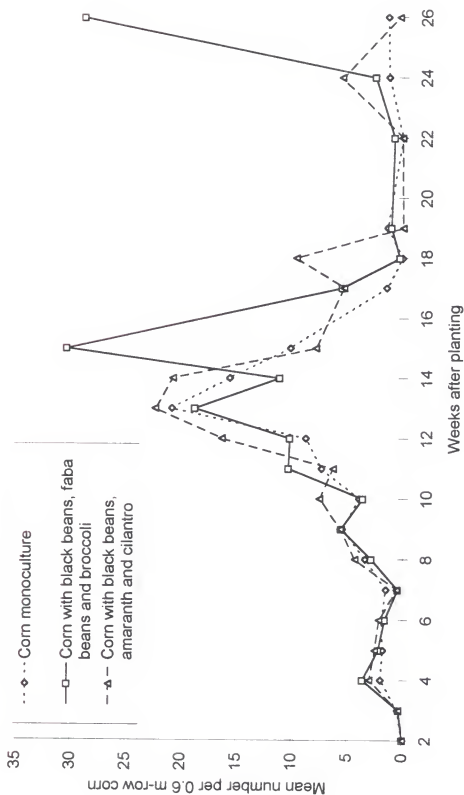


Figure A-2. Mean densities of aphids from corn in monoculture, corn intercropped with black beans, faba beans and broccoli, and corn intercropped with black beans, amaranth and cilantro, during the rainy season of 1996.

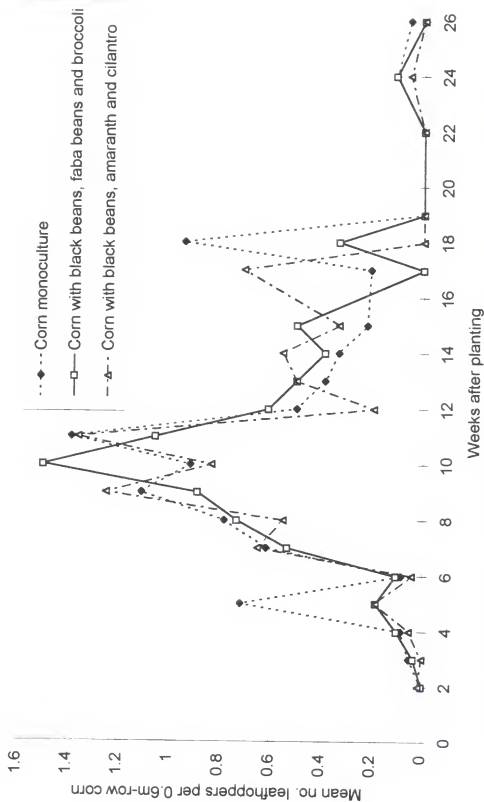


Figure A-3. Mean densities of leafhoppers from corn in monoculture, corn intercropped with black beans, faba beans and broccoli, and corn intercropped with black beans, amaranth and cilantro, during the rainy season of 1996.

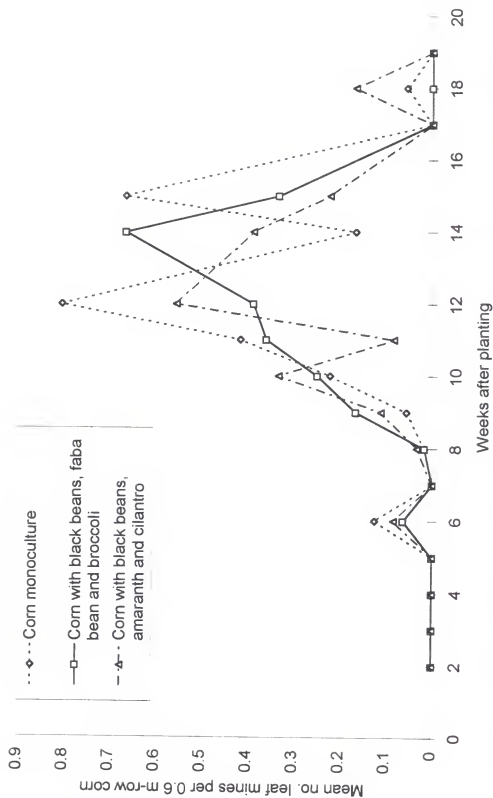


Figure A-4. Mean densities of leafmines from *Liriomyza commelinae*, *Liriomyza* sp., and *Agromyza* sp. from corn in monoculture, corn intercropped with black beans, faba beans and broccoli, and corn intercropped with black beans, amaranth and cilantro, during the rainy season of 1996.

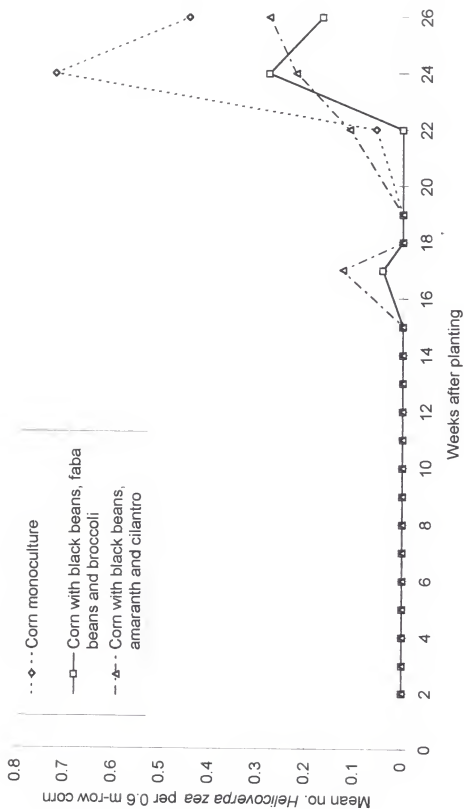


Figure A-5. Mean densities of *Helicoverpa zea* larvae from corn in monoculture, corn intercropped with black beans, faba beans and broccoli, and corn intercropped with black beans, amaranth and cilantro, during the rainy season of 1996.

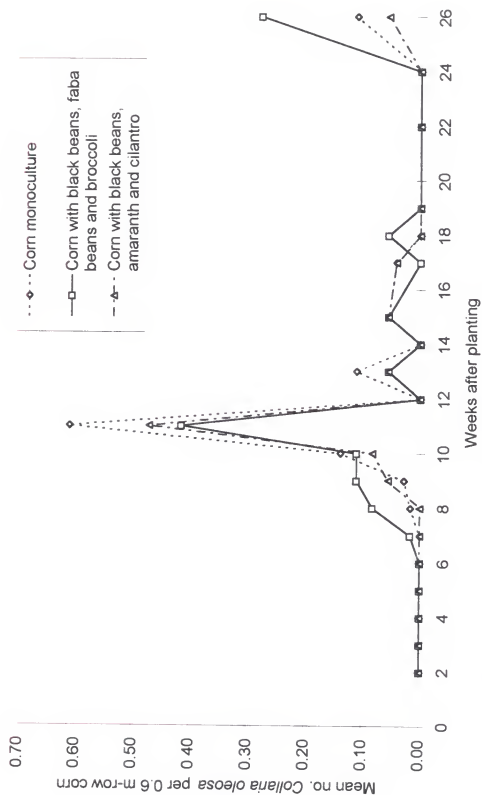


Figure A-6. Mean densities of *Collaria oleosa* adults from corn in monoculture, corn intercropped with black beans, faba beans and broccoli, and corn intercropped with black beans, amaranth and cilantro, during the rainy season of 1996.

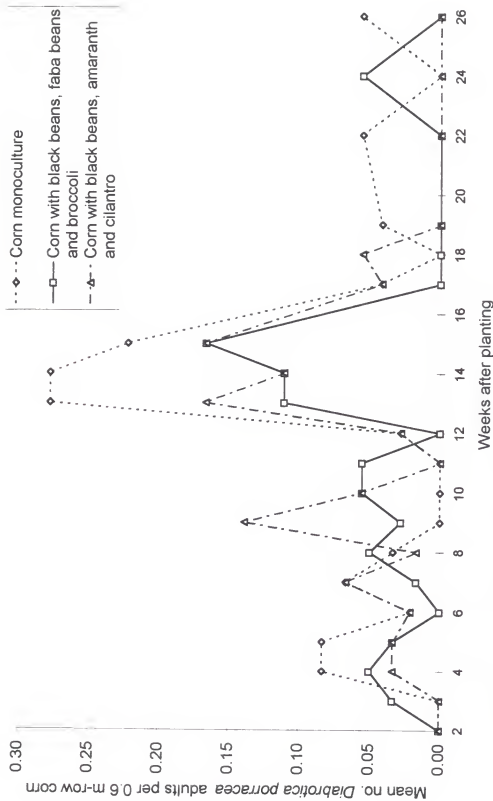


Figure A-7. Mean densities of *Diabrotica porracea* adults from corn in monoculture, corn intercropped with black beans, faba beans and broccoli, and corn intercropped with black beans, amaranth and cilantro, during the rainy season of 1996.



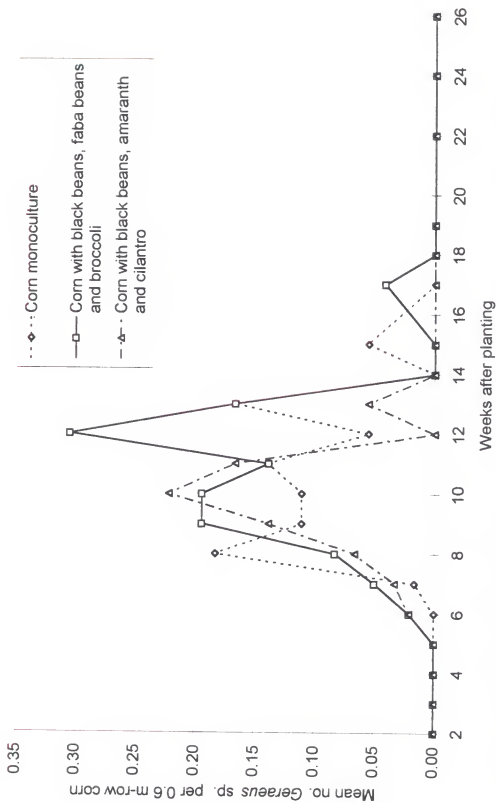


Figure A-8. Mean densities of *Geraeus* sp. adults from corn in monoculture, corn intercropped with black beans, faba beans and broccoli, and corn intercropped with black beans, amaranth and cilantro, during the rainy season of 1996.

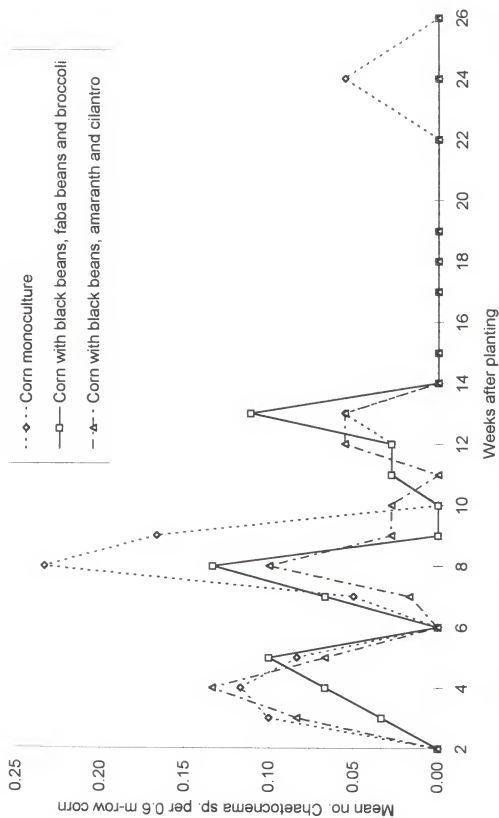


Figure A-9. Mean densities of *Chaetocnema* sp. adults from corn in monoculture, corn intercropped with black beans, faba beans and broccoli, and corn intercropped with black beans, amaranth and cilantro, during the rainy season of 1996.

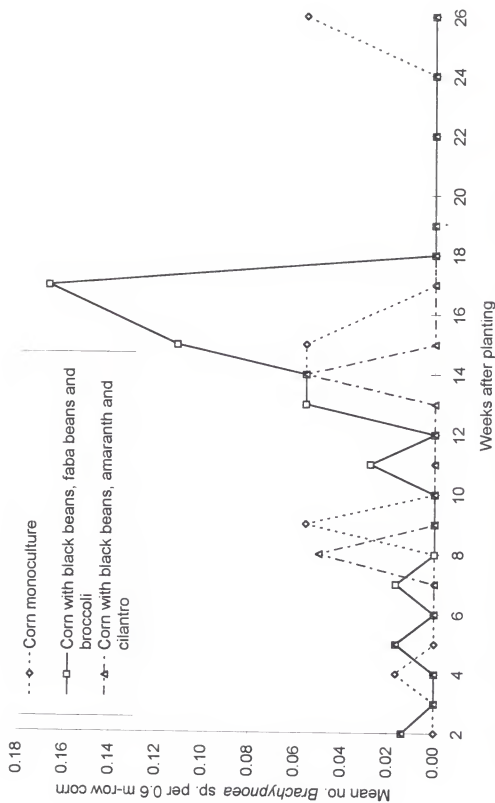


Figure A-10. Mean densities of *Brachyprnoea* sp. adults from corn in monoculture, corn intercropped with black beans, faba beans and broccoli, and corn intercropped with black beans, amaranth and cilantro, during the rainy season of 1996.

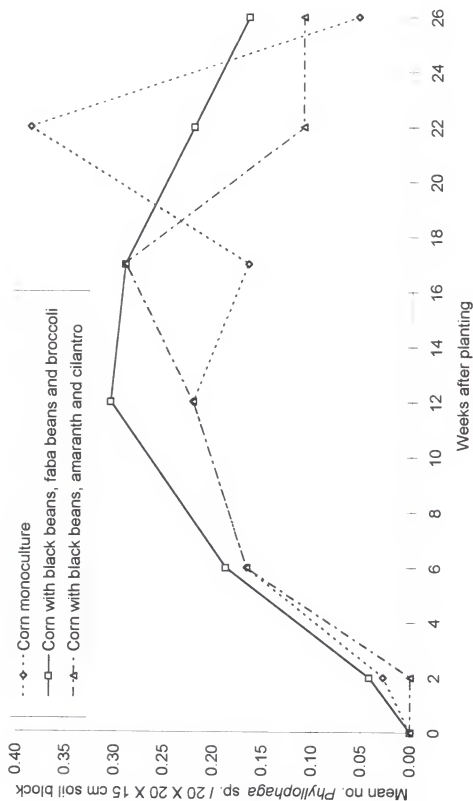


Figure A-11. Mean densities of *Phyllophaga* sp. eggs and larvae from soil of corn roots in monoculture, corn intercropped with black beans, faba beans and broccoli, and corn intercropped with black beans, amaranth and cilantro, during the rainy season of 1996.

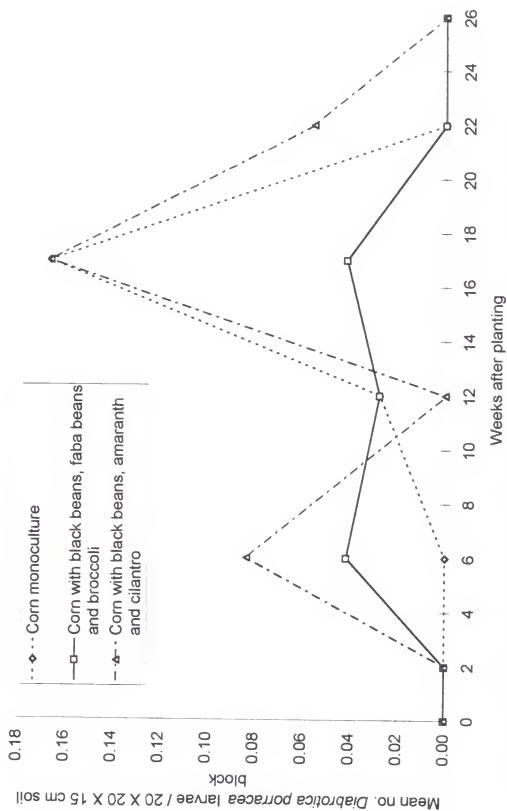


Figure A-12. Mean densities of *Diabrotica porracea* larvae from soil of corn roots in monoculture, corn intercropped with black beans, faba beans and broccoli, and corn intercropped with black beans, amaranth and cilantro, during the rainy season of 1996.

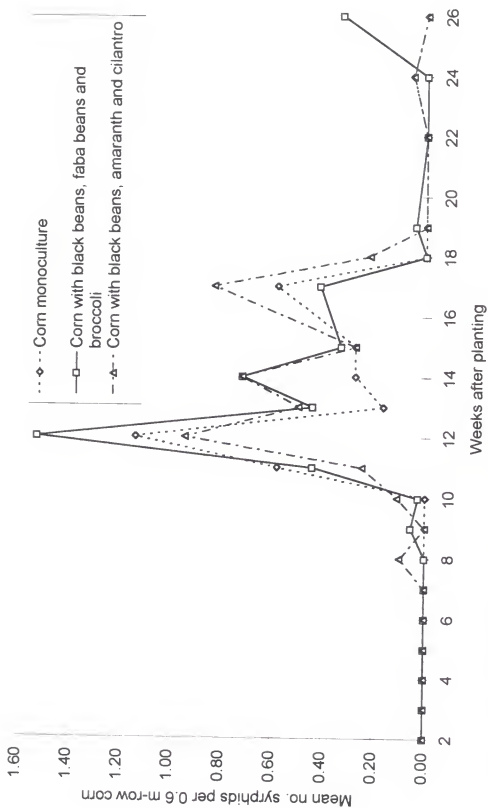


Figure A-13. Mean densities of syrphids (*Baccha* sp. and *Toxomerus* sp.) on corn in monoculture, corn intercropped with black beans, faba beans and broccoli, and corn intercropped with black beans, amaranth and cilantro, during the rainy season of 1996.

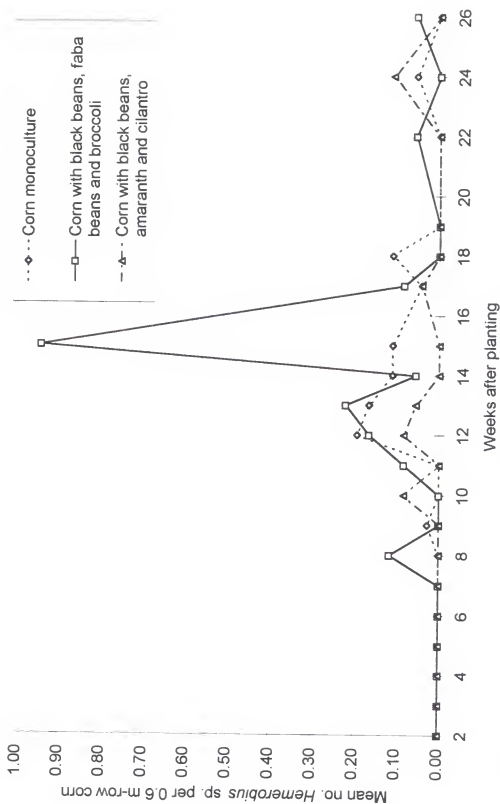


Figure A-14. Mean densities of *Hemerobius* sp. on corn in monoculture, corn intercropped with black beans faba beans and broccoli, and corn intercropped with black beans, amaranth and cilantro, during the rainy season of 1996

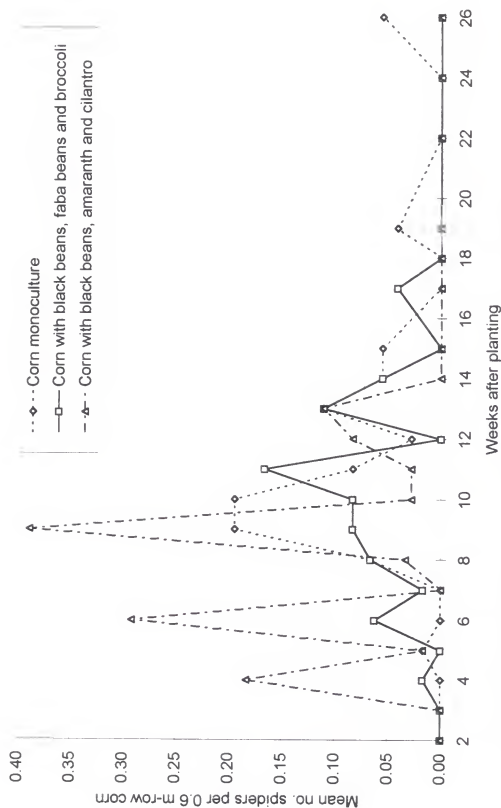


Figure A-15. Mean densities of spiders on corn in monoculture, corn intercropped with black beans, faba beans and broccoli, and corn intercropped with black beans, amaranth and cilantro, during the rainy season of 1996.



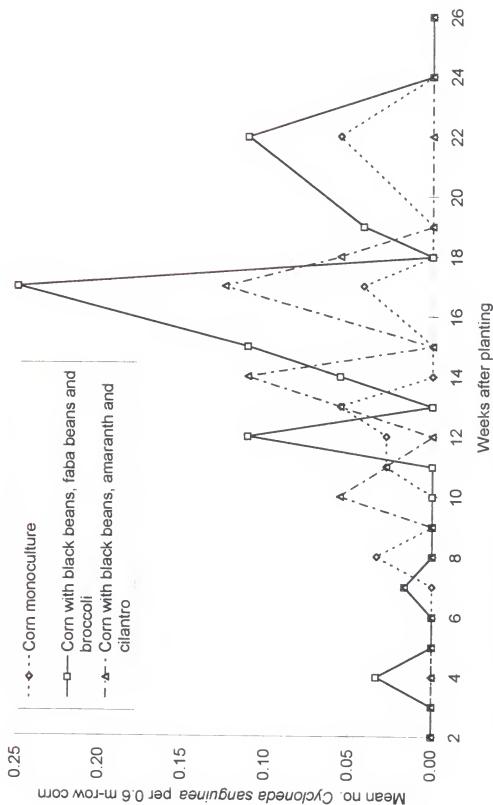


Figure A-16. Mean densities of *Cyclonea sanguinea* adults on corn in monoculture, corn intercropped with black beans, faba beans and broccoli, and corn intercropped with black beans, amaranth and cilantro, during the rainy season of 1996.

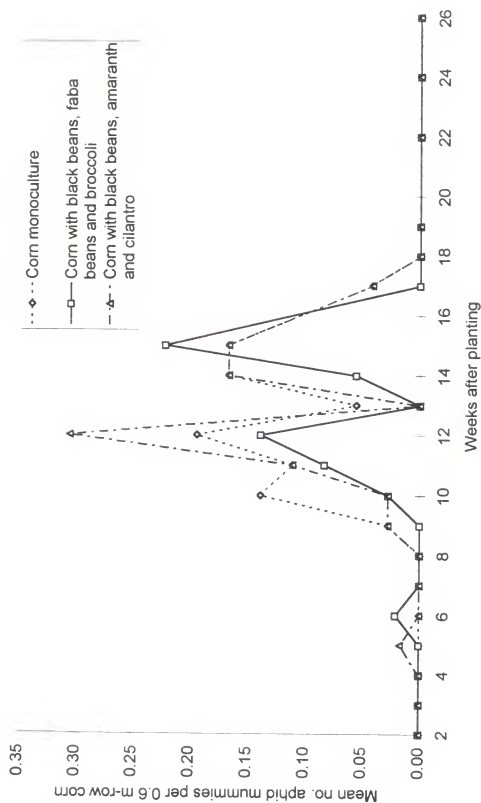


Figure A-17. Mean densities of aphid mummies on corn in monoculture, corn intercropped with black beans, faba beans and broccoli, and corn intercropped with black beans, amaranth and cilantro, during the rainy season of 1996.

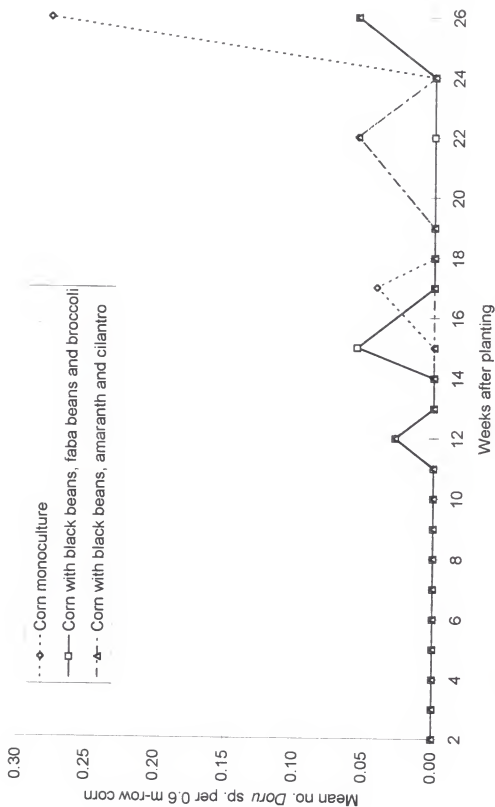


Figure A-18. Mean densities of *Doru* sp. on corn in monoculture, corn intercropped with black beans, faba beans and broccoli, and corn intercropped with black beans, amaranth and cilantro, during the rainy season of 1996

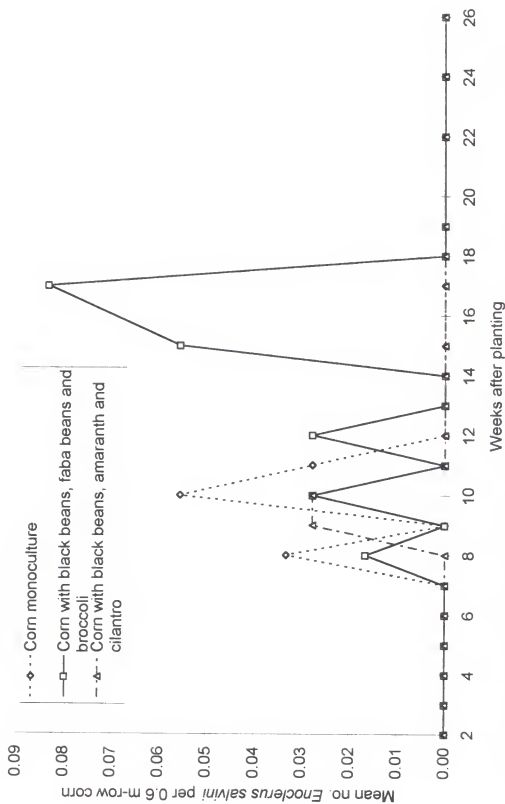


Figure A-19. Mean densities of *Enoclerus salvini* adults on corn in monoculture, corn intercropped with black beans, faba beans and broccoli, and corn intercropped with black beans, amaranth and cilantro, during the rainy season of 1996.

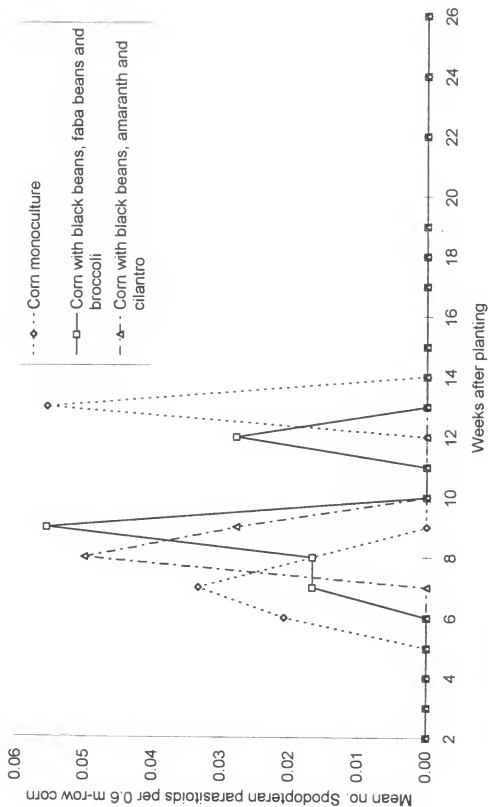


Figure A-20. Mean densities of parasitoids of *Spodoptera frugiperda* (*Campoplex* sp. and *Diadegma* sp.) adults on corn in monoculture, corn intercropped with black beans, faba beans and broccoli, and corn intercropped with black beans, amaranth and cilantro, during the rainy season of 1996.

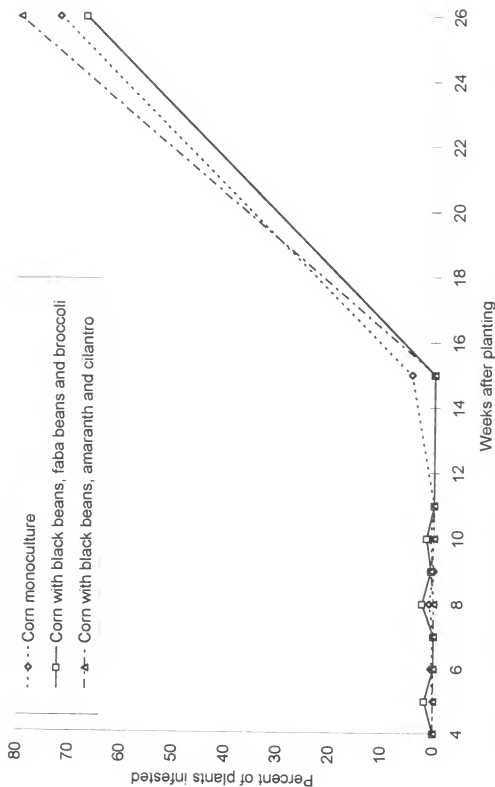


Figure A-21. Mean percent of plants infested with *Helminthosporium* sp. on corn in monoculture, corn intercropped with black beans, faba beans and broccoli, and corn intercropped with black beans, amaranth, and cilantro, during the rainy season of 1996.

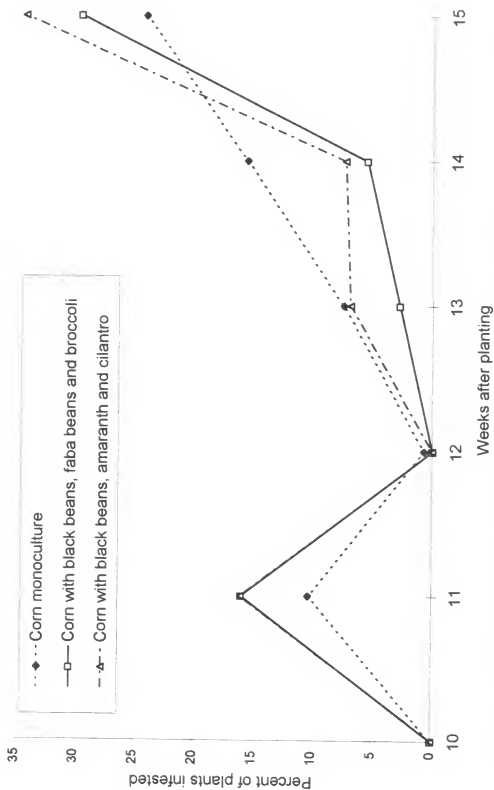


Figure A-22. Mean percent of plants infested with *Phyllachora maydis* Maubl. on corn in monoculture, corn intercropped with black beans, faba beans and broccoli, and corn intercropped with black beans, amaranth, and cilantro, during the rainy season of 1996.

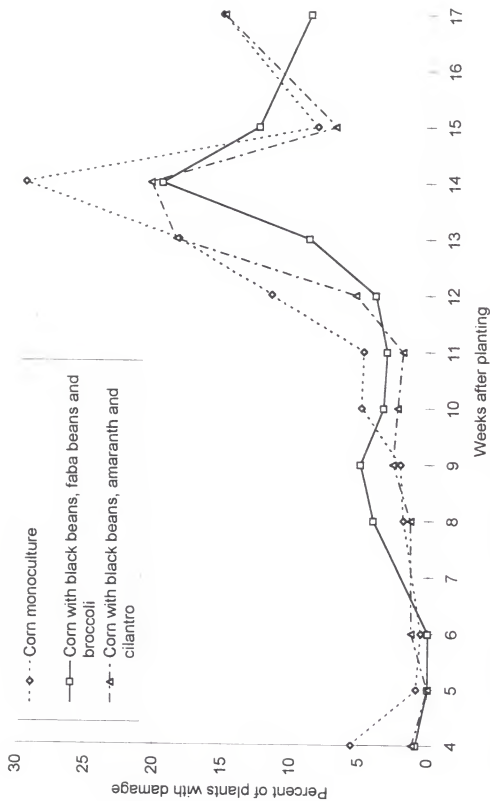


Figure A-23. Mean percent of plants with damage from *Spodoptera frugiperda* on corn in monoculture, corn intercropped with black beans, faba beans and broccoli, and corn intercropped with black beans, amaranth, and cilantro, during the rainy season of 1996.



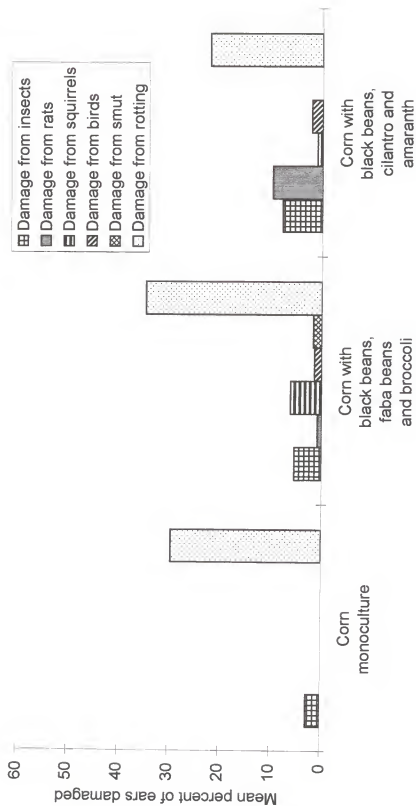


Figure A-24. Percent of ears damaged, by source, in corn moniculture, corn intercropped with black beans, faba beans and broccoli, and corn intercropped with black beans, cilantro and amaranth, October 17, 1996.

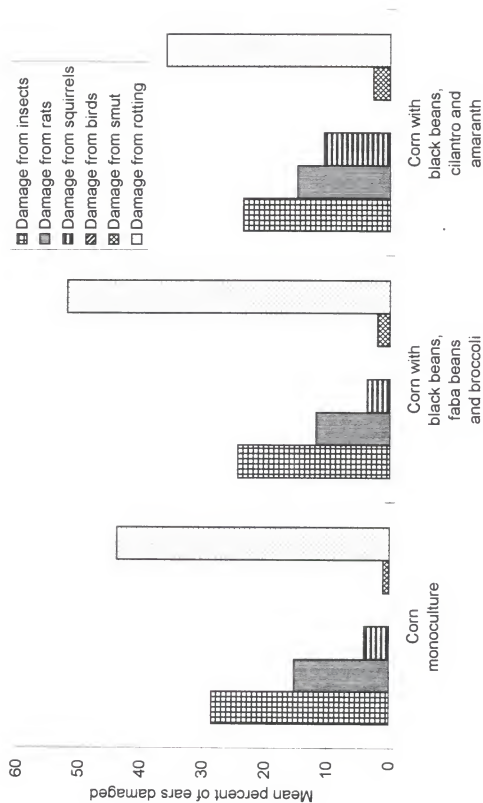


Figure A-25. Percent of ears damaged, by source, in corn monoculture, corn intercropped with black beans faba beans and broccoli, and corn intercropped with black beans, cilantro and amaranth, October 25, 1996.

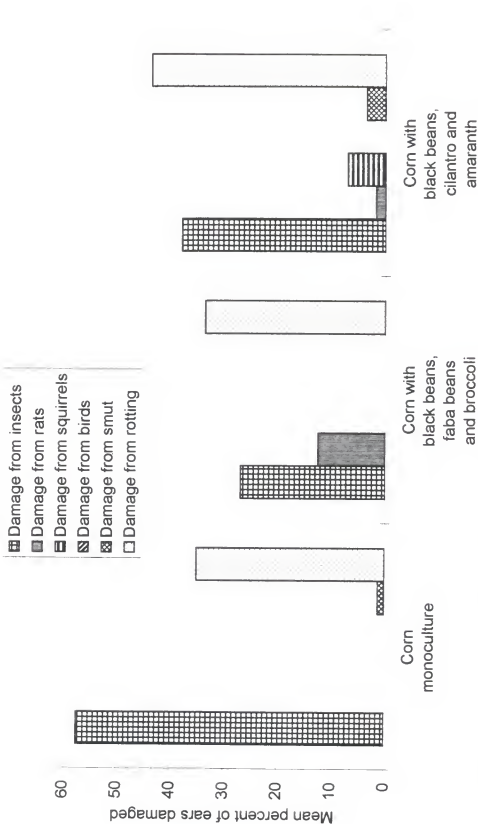


Figure A-26. Percent of ears damaged, by source, in corn monoculture, corn intercropped with black beans, faba beans and broccoli, and corn intercropped with black beans, cilantro and amaranth, October 31, 1996.

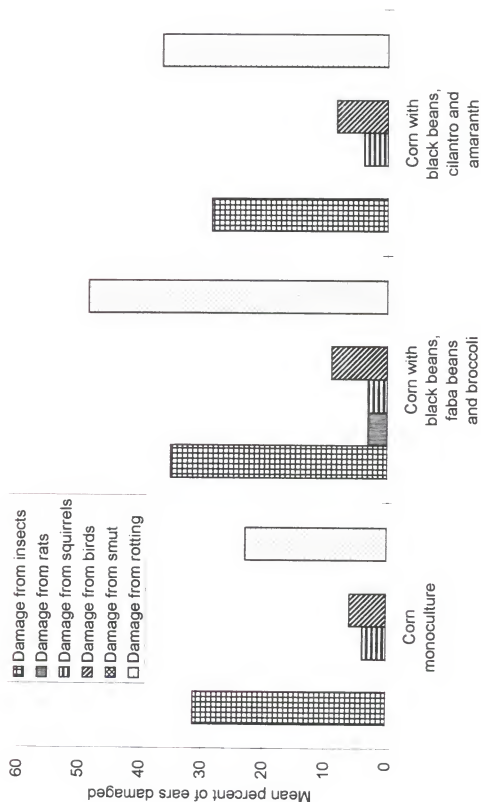


Figure A-27. Percent of ears damaged, by source, in corn monoculture, corn intercropped with black beans, faba beans and broccoli, and corn intercropped with black beans, cilantro and amaranth, November 13, 1996.

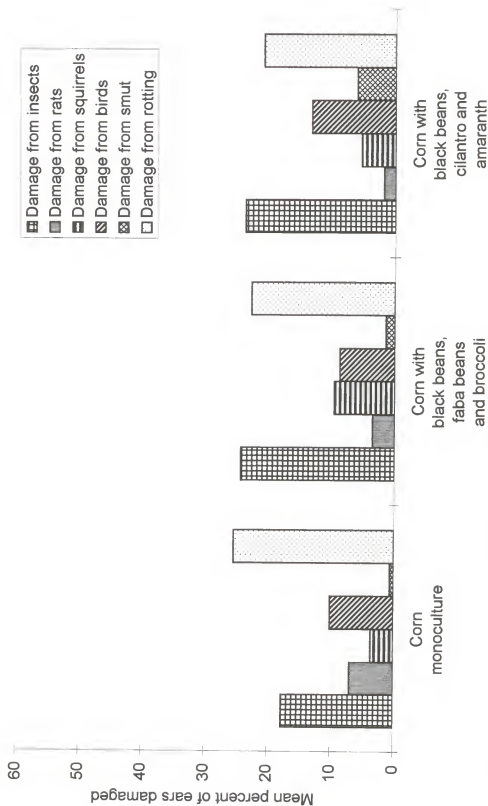


Figure A-28. Percent of ears damaged, by source, in corn monoculture, corn intercropped with black beans, faba beans and broccoli, and corn intercropped with black beans, cilantro and amaranth, November 26, 1996.

APPENDIX B  
DESCRIPTIONS OF SEASONAL TRENDS IN INSECT AND BENEFICIAL  
POPULATION DENSITIES, DISEASE AND DAMAGE ON BEAN IN  
MONOCULTURE AND ALTERNATIVE INTERCROPS

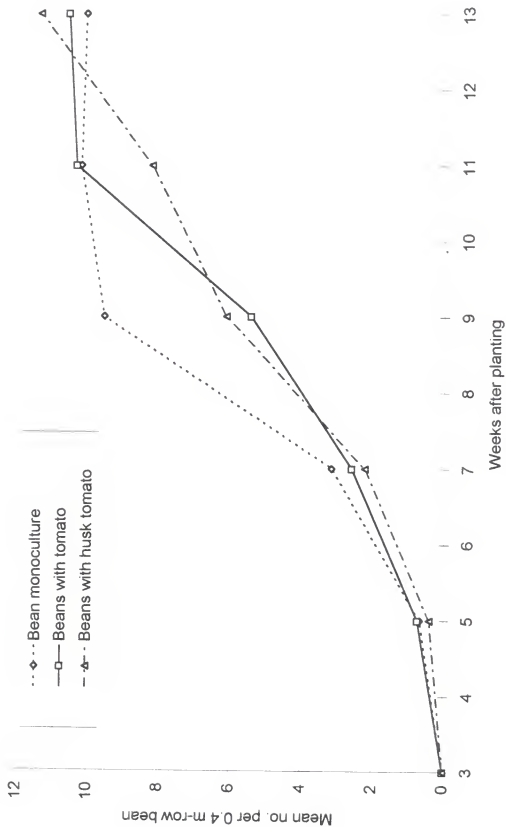


Figure B-1. Mean densities of *Liriomyza huidobrensis* mines on black beans in monoculture, intercropped with tomato, and intercropped with husk tomato, during the dry season of 1997.

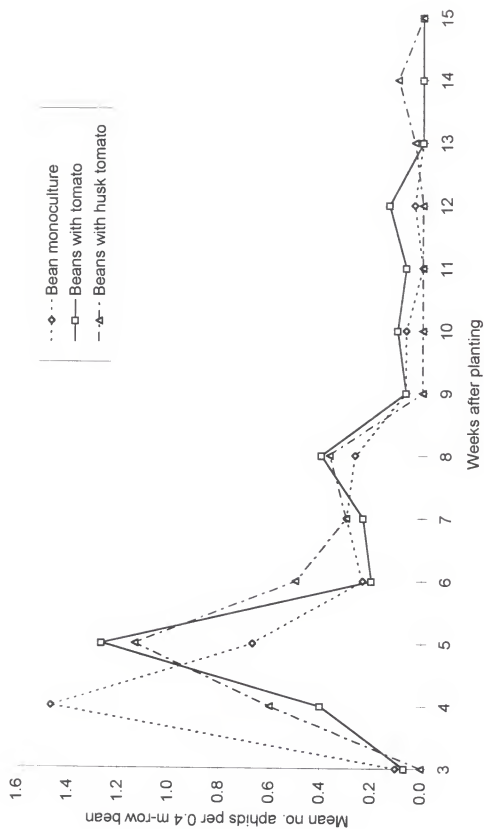


Figure B-2. Mean densities of aphids on black beans in moniculture, intercropped with tomato, and intercropped with husk tomato, during the dry season of 1997.



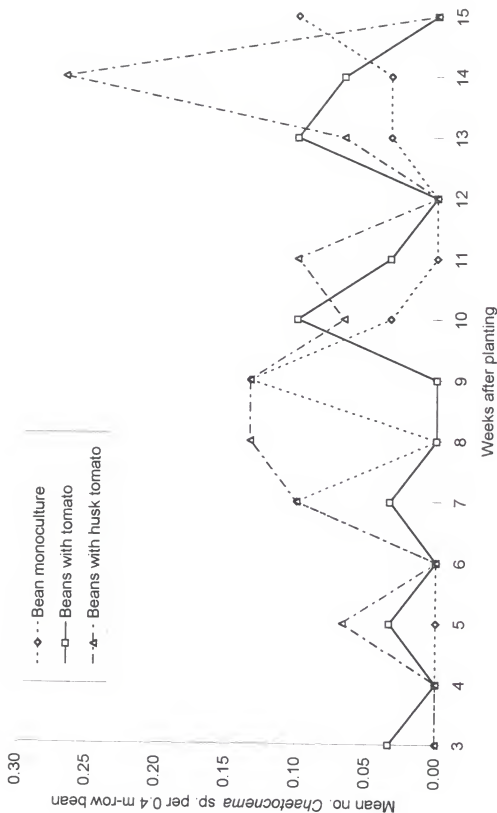


Figure B-3. Mean densities of *Chaetocnema* sp. adults on black beans in monoculture, intercropped with tomato, and intercropped with husk tomato, during the dry season of 1997.

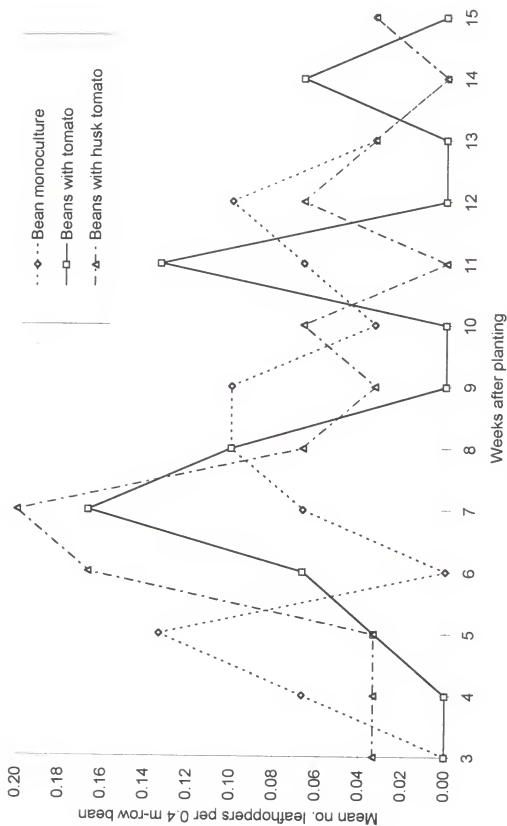


Figure B-4. Mean densities of leafhoppers on black beans in monoculture, intercropped with tomato, and intercropped with husk tomato, during the dry season of 1997.

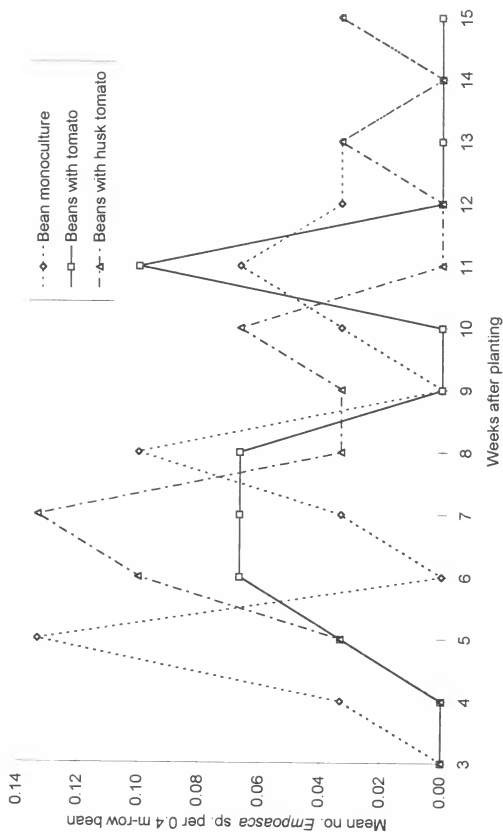


Figure B-5. Mean densities of *Empoasca* sp. on black beans in monoculture, intercropped with tomato, and intercropped with husk tomato, during the dry season of 1997.

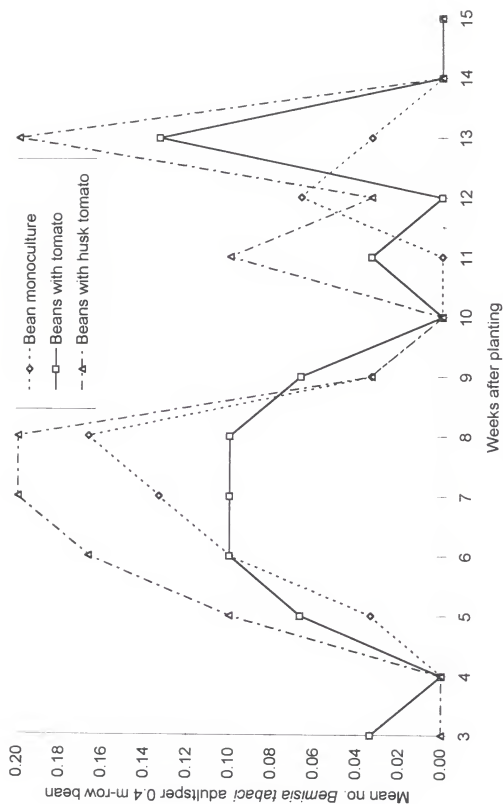


Figure B-6. Mean densities of *Bemisia tabaci* adults on black beans in monoculture, intercropped with tomato, and intercropped with husk tomato, during the dry season of 1997.

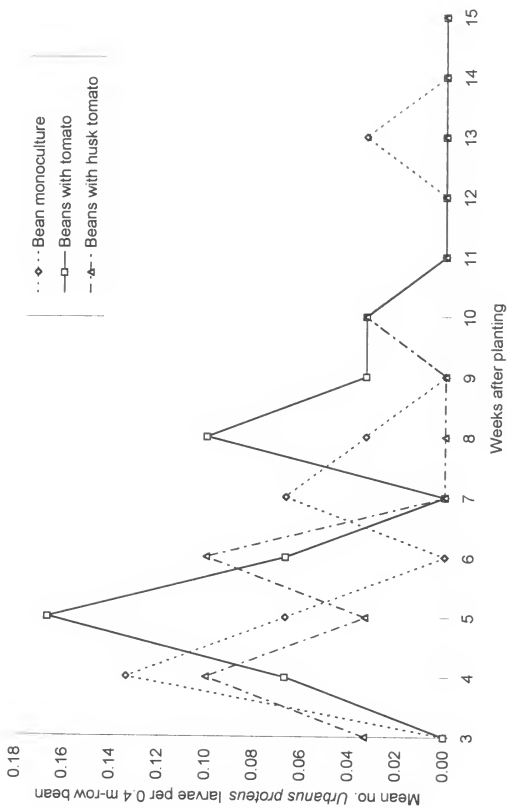


Figure B-7. Mean densities of *Urbanus proteus* on black beans in monoculture, intercropped with tomato, and intercropped with husk tomato, during the dry season of 1997.

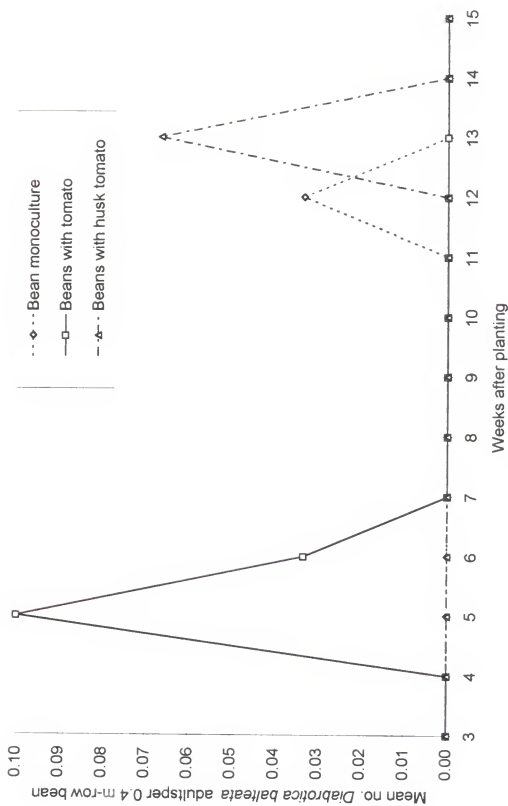


Figure B-8. Mean densities of *Diabrotica balteata* adults on black beans in monoculture, intercropped with tomato, and intercropped with husk tomato, during the dry season of 1997.

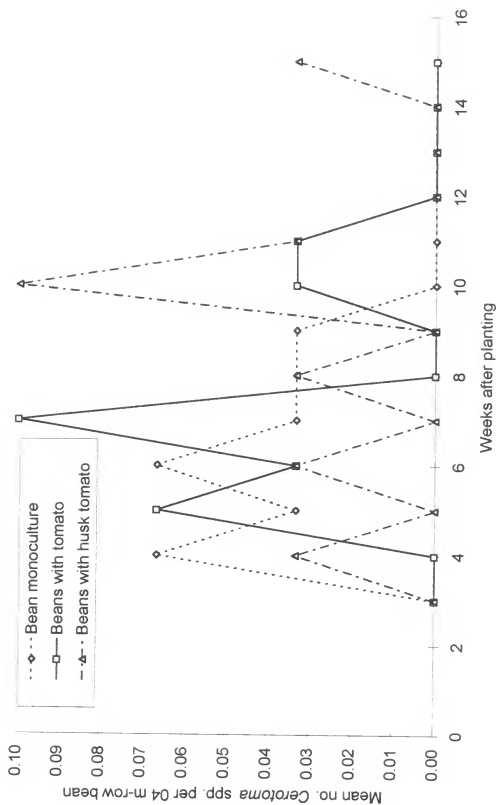


Figure B-9. Mean densities of *Cerotoma* spp. adults on black beans in monoculture, intercropped with tomato, and intercropped with husk tomato, during the dry season of 1997.

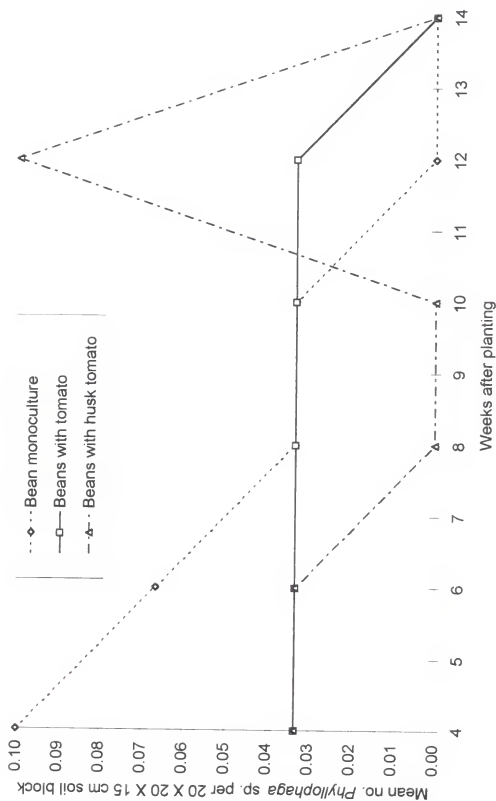


Figure B-10. Mean densities of *Phyllophaga* sp. eggs and larvae on black beans in monoculture, intercropped with tomato, and intercropped with husk tomato, during the dry season of 1997.



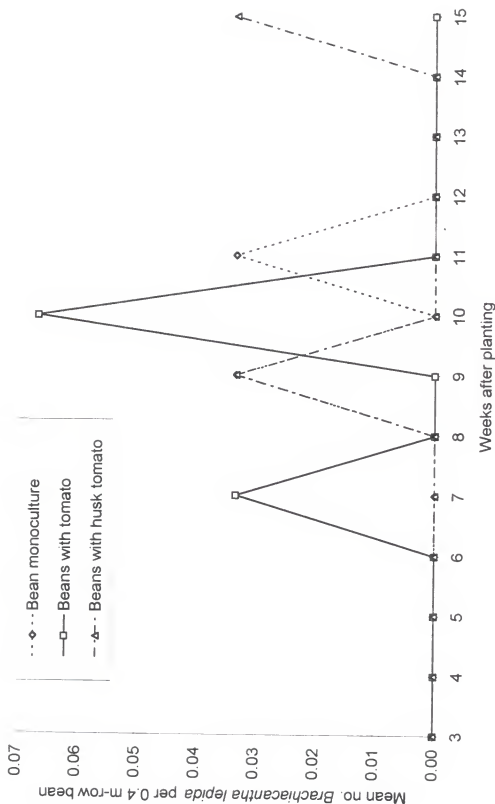


Figure B-11. Mean densities of coccinellids (*Brachycantha lepida* adults) on black beans in monoculture, intercropped with tomato, and intercropped with husk tomato, during the dry season of 1997.

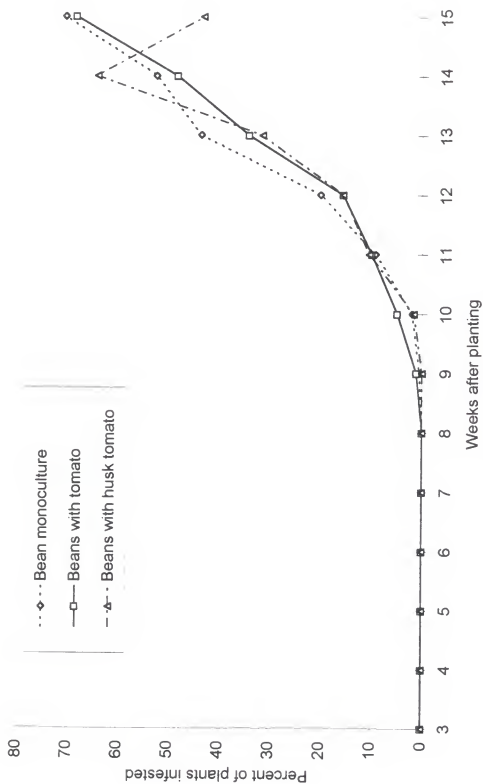


Figure B-12. Mean percent of black bean plants infested with bean rust (*Uromyces phaseoli*) when grown in monoculture, intercropped with tomato, and intercropped with husk tomato, during the dry season of 1997.

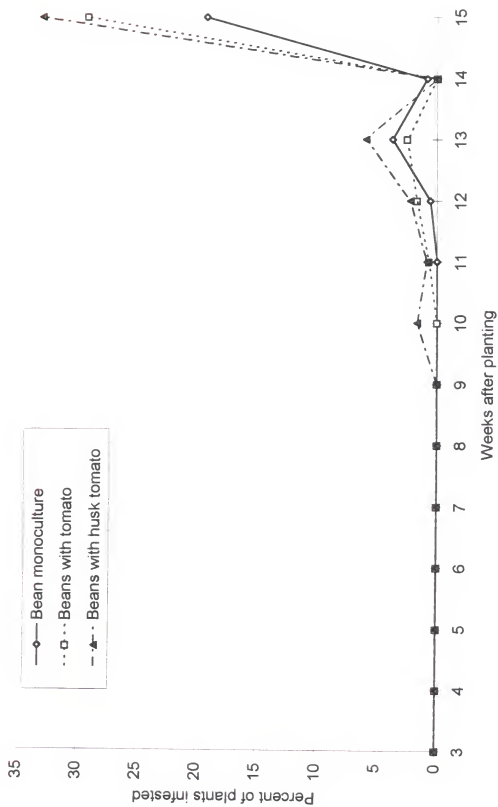


Figure B-13. Mean percent of black bean plants infested with leaf spot when grown in monoculture, intercropped with tomato, and intercropped with husk tomato, during the dry season of 1997.

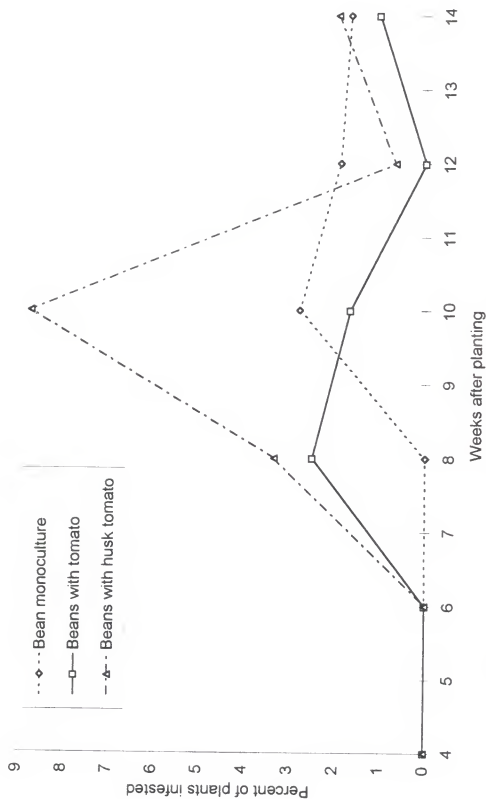


Figure B-14. Mean percent of black bean plants infested with root rot (*Rhizoctonia* sp.) when grown in monoculture, intercropped with tomato, and intercropped with husk tomato, during the dry season of 1997.

APPENDIX C  
DESCRIPTIONS OF SEASONAL TRENDS IN NEMATODE POPULATION  
DENSITIES IN CORN AND BEAN CROPPING SYSTEMS

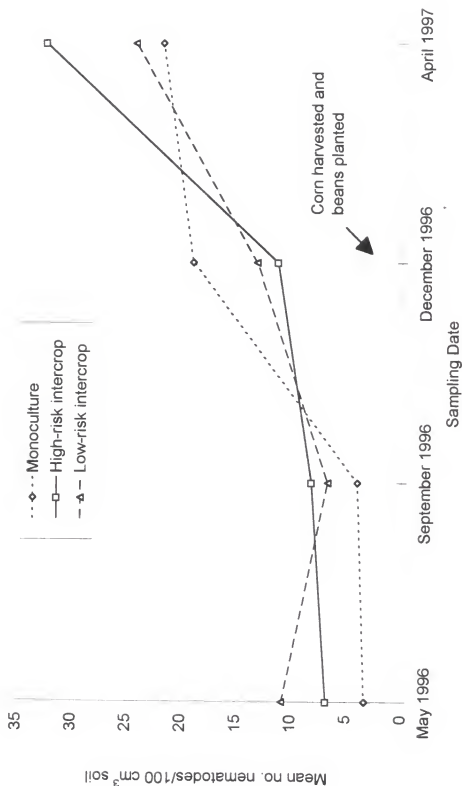


Figure C-1. Densities of *Helicotylenchus* spp. in soil samples from monocultures (corn followed by bean) and two alternative intercroppings (high-risk intercrop of corn with black beans, faba beans and broccoli, followed by black beans and tomato; low-risk intercrop of corn with black beans, cilantro and amaranth, followed by black beans and husk tomato).

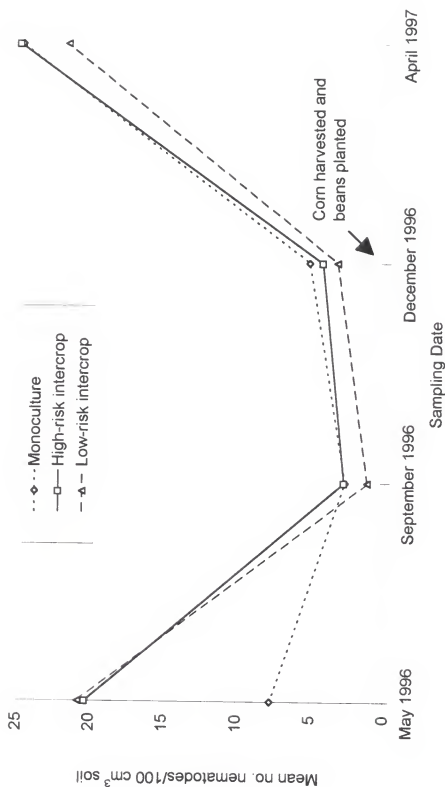


Figure C-2. Densities of *Meloidogyne* spp. in soil samples from monocultures (corn followed by bean) and two alternative intercrops (high-risk intercrop of corn with black beans, faba beans and broccoli, followed by black beans and tomato; low-risk intercrop of corn with black beans, cilantro and amaranth, followed by black beans and husk tomato).

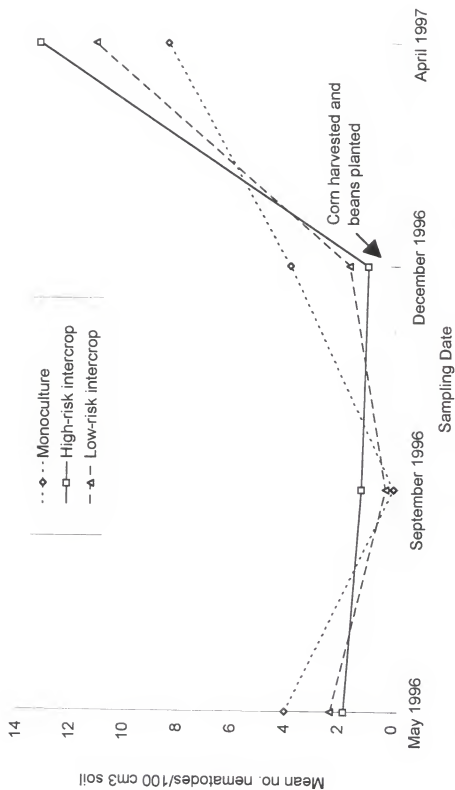


Figure C-3. Densities of *Pratylenchus* spp. in soil samples from monocultures (corn followed by bean) and two alternative intercroppings (high-risk intercrop of corn with black beans, faba beans and broccoli, followed by black beans and tomato; low-risk intercrop of corn with black beans, cilantro and amaranth, followed by black beans and husk tomato).



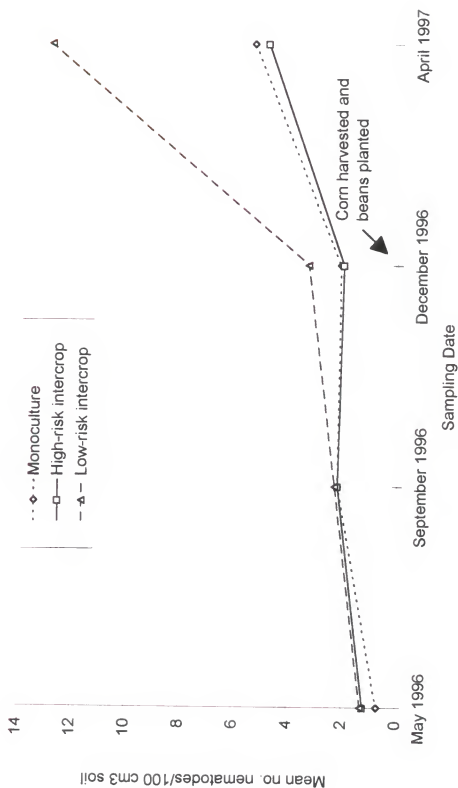


Figure C-4. Densities of *Trichodorus* spp. in soil samples from monocultures (corn followed by bean) and two alternative intercrops (high-risk intercrop of corn with black beans, faba beans and broccoli, followed by black beans and tomato; low-risk intercrop of corn with black beans, cilantro and amaranth, followed by black beans and husk tomato).

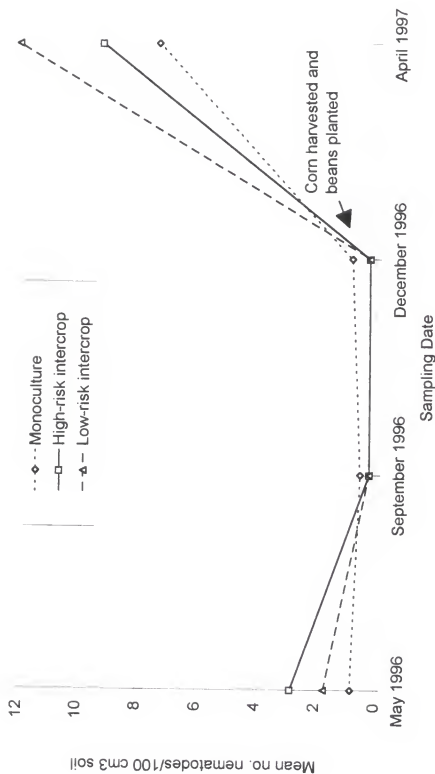


Figure C-5. Densities of *Tylenchostrongylus* spp. in soil samples from monocultures (corn followed by bean) and two alternative intercrops (high-risk intercrop of corn with black beans, faba beans and broccoli, followed by black beans and tomato; low-risk intercrop of corn with black beans, cilantro and amaranth, followed by black beans and husk tomato).

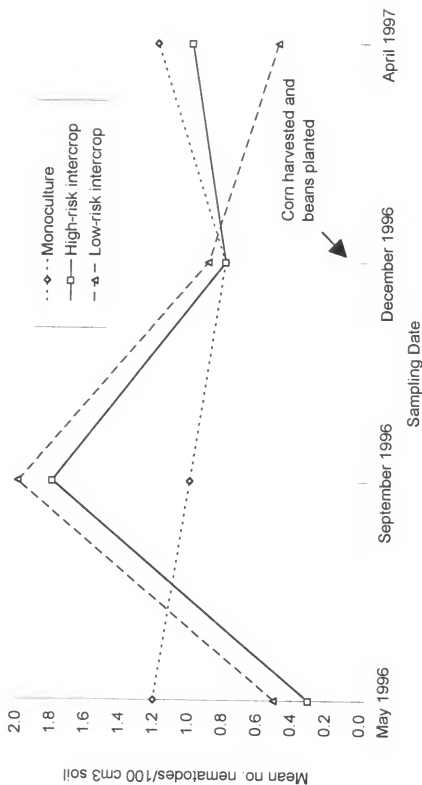


Figure C-6. Densities of *Hemicyclophora* spp. in soil samples from monocultures (corn followed by bean and two alternative intercrops (high-risk intercrop of corn with black beans, faba beans and broccoli, followed by black beans and tomato; low-risk intercrop of corn with black beans, cilantro and amaranth, followed by black beans and husk tomato).

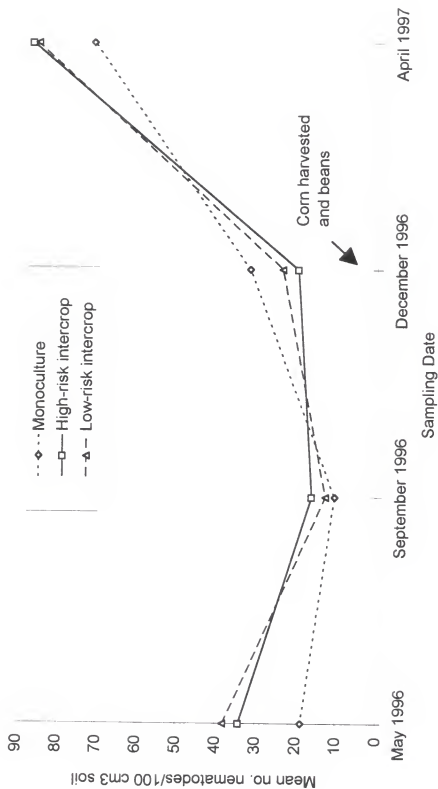


Figure C-7. Densities of plant parasitic nematodes in soil samples from monocultures (corn followed by bean) and two alternative intercrops (high-risk intercrop of corn with black beans, faba beans and broccoli, followed by black beans and tomato; low-risk intercrop of corn with black beans, cilantro and amaranth, followed by black beans and husk tomato).

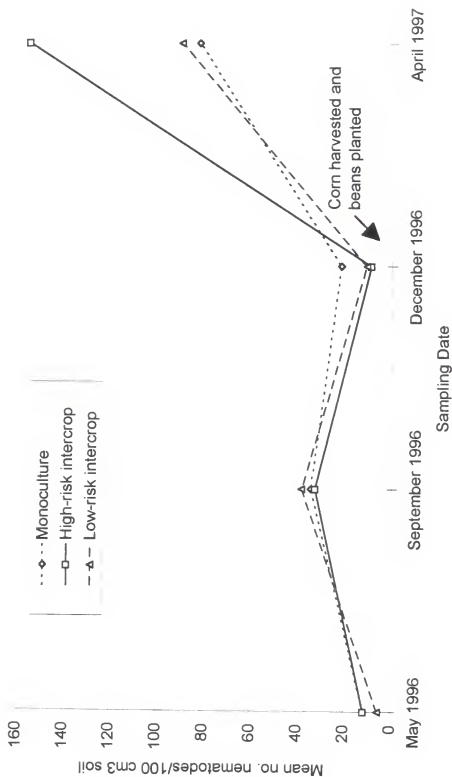


Figure C-8. Densities of bacterivorous nematodes in soil samples from monocultures (corn followed by bean) and two alternative intercroppings (high-risk intercrop of corn with black beans, faba beans and broccoli, followed by black beans and tomato; low-risk intercrop of corn with black beans, cilantro and amaranth, followed by black beans and husk tomato).

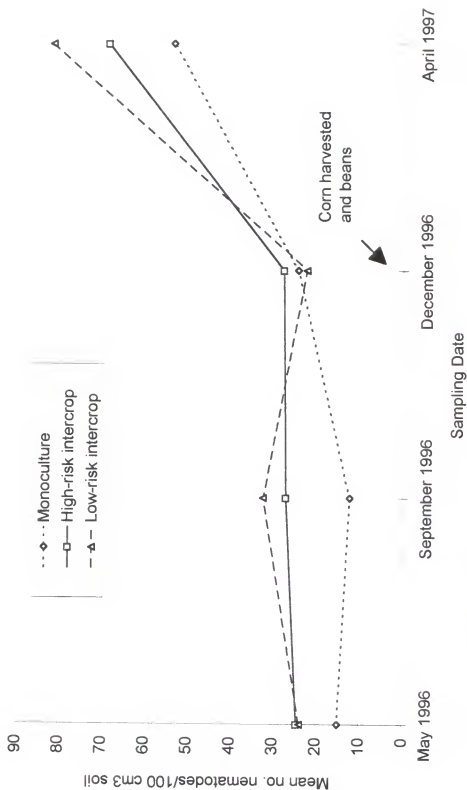


Figure C-9. Densities of fungivorous nematodes in soil samples from monocultures (corn followed by bean) and two alternative intercroppings (high-risk intercrop of corn with black beans, faba beans and broccoli, followed by black beans and tomato; low-risk intercrop of corn with black beans, cilantro and amaranth, followed by black beans and husk tomato).

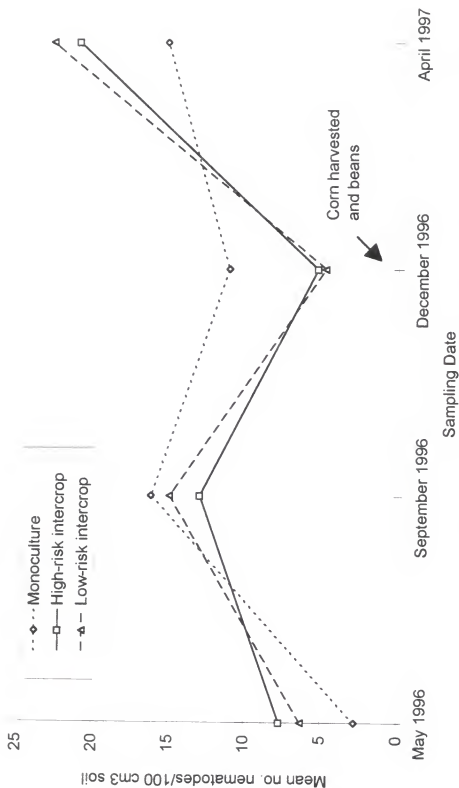


Figure C-10. Densities of omnivorous nematodes in soil samples from monocultures (corn followed by bean) and two alternative intercrops (high-risk intercrop of corn with black beans, faba beans and broccoli, followed by black beans and tomato; low-risk intercrop of corn with black beans, cilantro and amaranth, followed by black beans and husk tomato).

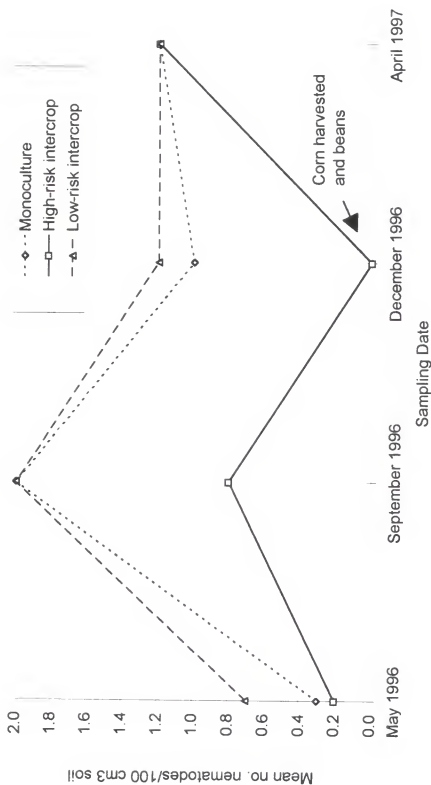


Figure C-11. Densities of predatory nematodes in soil samples from monocultures (corn followed by bean) and two alternative intercroppings (high-risk intercrop of corn with black beans, faba beans and broccoli, followed by black beans and tomato; low-risk intercrop of corn with black beans, cilantro and amaranth, followed by black beans and husk tomato).



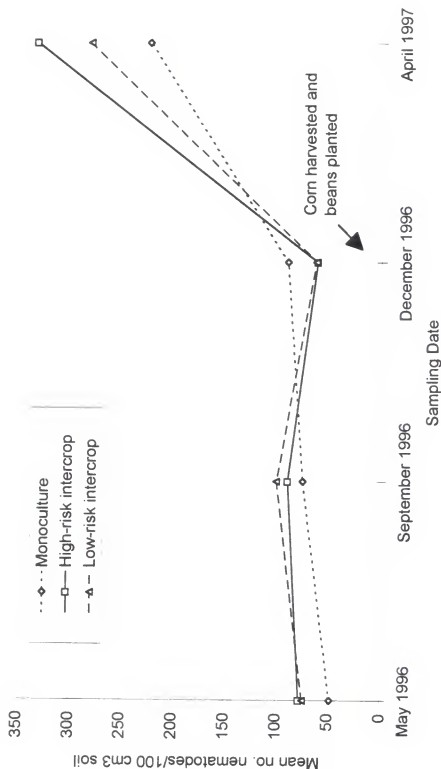


Figure C-12. Densities of total nematodes in soil samples from monocultures (corn followed by bean) and two alternative intercrops (high-risk intercrop of corn with black beans, faba beans and broccoli, followed by black beans and tomato; low-risk intercrop of corn with black beans, cilantro and amaranth, followed by black beans and husk tomato).

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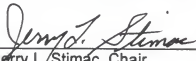


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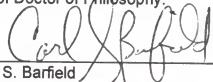
## BIOGRAPHICAL SKETCH

Barbra C. Larson Vasquez was born 22 December 1964 in Madrid, Spain, and raised in Wayne, New Jersey. After attending Wayne Valley High School, she completed the B.A. degree in biology and interdisciplinary studies(Third World development) at Amherst College. After two years as a Peace Corps volunteer in Guatemala, she entered a graduate program in entomology at Rutgers University, receiving the M.S. degree in 1991. She worked in the Biology Department and the Center for Environmental Studies at the Universidad del Valle de Guatemala during 1993 before entering the entomology Ph.D. program at the University of Florida in 1994.

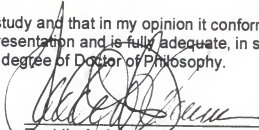
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Jerry L. Stimac, Chair  
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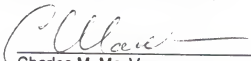
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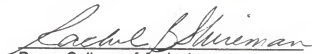
  
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